Contrasting Vegetation and Fire Histories on the Point Reyes Peninsula During the Pre-Settlement and Settlement Periods: 15,000 Years of Change

Final Report

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INTRODUCTION

The relationship between fire occurrence, climate change, vegetation composition and human impact has attracted considerable interest from a wide variety of professionals. As landscapes have become increasingly fragmented and modified by human activities, and regions of "natural vegetation" have become smaller and rarer, the importance of paleoecological research for determining former vegetation patterns and fire regimes has increased. Such retrospective studies are becoming a critical resource for land managers to determine appropriate strategies to restore "natural" vegetation to National Parks, and re-introduce natural processes such as fire into locations modified by recent human impacts and fire exclusion policies.

Retrospective studies of Point Reyes landscapes can take many forms, and provide data on numerous timescales. Historical records and ethnographic studies can document ecosystem change over the past decades to centuries (Treganza 1961; Duncan 1992). For studying fire history, analysis of fire-scarred living trees and stumps can extend the history of fire disturbance considerably, perhaps from hundreds of years to a millennium (Finney 1990; Brown et al. 1999). Examination of charcoal and plant remains in stratigraphic sediments (found in small ponds, vernal pools and other moist places) can extend the record of vegetation history (Rypins et al. 1989), fire disturbance and ecosystem effects to more ancient times – beyond the period provided by other proxy records (Whitlock & Anderson 2003). Burning of vegetation produces abundant charred particles, which are subsequently deposited in ponds, pools and wetlands through the action of air currents and water movements across the landscape. These charcoal particles are the direct evidence of former fires within the vicinity. Similarly, plants growing near the pools and wet places leave a fossil record in the form of their pollen, which is often specific to species and genera, and which in aggregate can characterize plant communities (Russell 1983). Analysis of all kinds of proxy records assists in providing an integrated picture of ecosystem change.

The goal of sedimentary fire history studies in Point Reyes National Seashore is to document the long-term fire history of several vegetation types with enough spatial and temporal resolution to extend the reconstructions provided by historical records (Livingston 1994, 1995), ethnographic evidence and dendrochronological records (Finney 1990; Brown et al. 1999). Such longer records allow an opportunity to investigate the relationship between periods of differing climate in the past and potential changes in disturbance regime. Perceptions gained from this research are important in understanding the legacy of past fires in present ecosystems (Whitlock & Anderson 2003) as well as the role of fire disturbance in future climate changes (Overpeck et al. 1990; Price & Rind 1994; Brunelle & Anderson 2003).

Three paleoecological studies directed at the history of vegetation change have been conducted on the Point Reyes Peninsula, although only one of these included data on the history of fire. Rypins et al. (1989) examined three sites, and the combined record provided evidence of vegetation change over the last ca. 12,300 radiocarbon years. Coastal exposures as well as a stratigraphic profile from Coast Trail Pond suggested that vegetation changed from a Douglas-fir (*Pseudotsuga menzeisii*) – fir (*Abies*) forest to coastal sage scrub and grassland between ca. 10,300 and 9,400 radiocarbon years ago. Stratigraphic evidence suggested to Rypins et al. that this Pleistocene- Holocene transition was characterized by more frequent high intensity storms.

Russell (1983) studied the pollen and charcoal from a sediment core from Wildcat Lake, located near the southwest tip of Point Reyes National Seashore. Although the sediments were not dated directly, hypothesized sediment accumulation rates suggested that the core covered the last ca. 900 years. Russell (1983) used changes in the proportion of grass (Poaceae) and shrub pollen to determine that the importance of grassland and sage scrub vegetation alternated over the last millennium, even before the arrival of Europeans within the area. Charcoal particles identified from pollen slides showed fewer charcoal deposited above ca. 35 cm depth, but an estimate of the age of this depth was not provided.

Duncan's (1992) dissertation included pollen analysis of several sites in Marin County, including Mud Pond within Point Reyes National Seashore. Her research revolved primarily around the vegetation and ethnobotanical uses of plants by the Miwok at the time of European contact. Mud Pond records vegetation changes over the last ca. 1000 years.

Present fieldwork was initiated in October, 1998, with a second visit to PORE in May, 2002. In order to sample sites in as many vegetation types as possible, we collected sediment cores from five locations. These sites are found from near sea-level in grassland – scrubland to ca. 230 m in coastal sage scrub mixed conifer (Douglas-fir – coast redwood [*Sequoia sempervirens*]) – oak [*Quercus*] forest.

Pollen preservation in these cores was very good and charcoal particles were abundant in all records. Pollen analysis has allowed us to determine the vegetation history of PORE in a comprehensive manner, while analysis of the charcoal particle stratigraphy has provided us with a unique opportunity to reconstruct the long-term fire history of very different vegetation types within Point Reyes National Seashore.

THE STUDY SITES

The lowest elevation site is Creamery Bay Bog (informal name), located at ca.6 m above sea level at the head of Creamery Bay (Fig. 1; Table 1). The site has long been part of a cattle-raising dairy farm, called the "K" Ranch, and was probably the oldest ranch site on the Point (Livingston 1994). Located adjacent to the old Schooner Landing, the ranch served as the center of commerce for all of the Point Reyes dairies well into the 1920's. Presently the study site is a wet meadow, surrounded primarily by California annual grassland (Fig. 1; Table 2). The dominant herbs include *Hydrocotle ranunculoides*, *Hypericum anagalloides* and various grasses growing on the marsh surface. Less common species include members of the sedge (Cyperaceae), rush (Juncaceae), and sunflower (Asteraceae) families, as well as *Galium trifidum* var. *pacificum*, *Mimulus guttatus*, *Plantago major*, *Potentilla anserina*, and *Ranunculus flammula*. Drier areas away from the marsh support coyote brush (*Baccharis pilularis*), wax myrtle (*Myrica californica*), salmonberry (*Rubus spectabilis*), California blackberry (*R. ursinus*), *Calamagrostis nutkaensis*, *Erechtites minima*, *Juncus effusus*, and *Pteridium aquilinum*. Terminology follows Hickman (1993).

Shutter Ridge Pond (informal name) is located near the Park Headquarters, at ca. 35 m above sea level, also in California annual grassland (Fig. 2; Table 1). The site is situated on a push ridge between two expressions of the San Andreas Fault, and was probably formed by differential movement along that fault, which squeezed the terrain to its present position. The site was originally settled by the Garcia family, then probably became part of Shafter's "W" Ranch in the 1860's. Thus, this may have been one of the earliest settled sites in the area (Livingston 1994). When cored in May 2002, the pond had nearly a meter of water (Table 1), but was dry during the vegetation census of October 2004 (Table 2). Wetland plants include sedges (*Carex*), grasses (*Agrostis*, *Distichlis*), rushes (*Juncus effusus*) and members of the sunflower family (*Gnaphalium palustre*, *Xanthium spinosum*, *Anthemis cotula*), with *Sparganium*, *Rumex conglomeratus*, *Mentha pulegium* and others. Uplands herbs were dominated by grasses (*Holcus* *lanatus*, *Lolium multiflorum*, *Cynosurus echinatus*, *Avena barbata*, and others), *Plantago lanceolata*, *Rumex acetosella*, *Cirsium vulgare*, and *Pteridium aquilinum*, among others. Coyote brush is present away from the wetland, as are coast live oak (*Quercus agrifolia*), California bay (*Umbellularia californica*), arroyo willow (*Salix lasiolepis*) and, growing along adjacent streams, red alder (*Alnus rubra*).

Wildcat Lake is adjacent to the Pacific Ocean at ca. 62 m elevation (Table 1), sitting on a complex landslide deposit covering ca. 2.6 km^2 (Clague 1969). The area just to the northwest of the lake was occupied as early as 1858 as the Wildcat Ranch (Livingston 1994). The area was used in the 1850's and 1860's for grazing cattle and horses, as well as tilled farming. The ranch is presently Wildcat Camp campground, with the original building removed and only a few *Eucalyptus* trees left to mark the spot. The overall characterization of the vegetation surrounding the pond is coastal scrub, dominated by California sagebrush and mugwort (*Artemisia californica, A douglasiana*), coyote brush and California coffeeberry (*Rhamnus californica*) (Fig. 3; Table 2). Common herbs and shrubs include numerous grasses, members of the sunflower family, oceanspray (*Holodiscus discolor*), honeysuckle (*Lonicera hispidula*), western poison oak (*Toxicodendron diversilobum*), among many others. A few individuals of Douglas-fir, California bay, and even Monterey pine (*Pinus radiata*) and blue gum (*Eucalyptus globulus*) occur near the lake. The nearshore vegetation is dominated by California blackberry, arroyo willow, bulrush (*Scirpus* sp.), *Juncus effusus*, *Equisetum*, and others (Table 2).

Glenmire (informal name) is a small wetland located immediately northwest of the Glen Campground. Elevation of Glenmire is ca. 167 m (Table 1). The region was part of the Shafter Ranches, South End Tract, though the origins of the adjacent Glen Ranch are "elusive" (Livingston 1994). However, by 1879 the ranch was a thriving dairy farm, like many others in the area. Today, Glenmire occurs within closed canopy Douglas-fir forest with California bay and oak (Fig. 4). Within the understory, and occurring in patches within the forest, are hazelnut (*Corylus cornuta* var. *californica*), California huckleberry (*Vaccinium ovatum*), coyote brush, California blackberry, western poison oak, and many herbs (Table 2). *Phalaris arundinacea* dominates the edge of the wetland, along with *Juncus effusus*, *Carex*, *Conium maculatum*, *Urtica dioica*, *Cirsium vulgare*, and others. Within the wetland itself *Sparganium eurycarpum*, *Juncus effusus* dominate, with *Glyceria leptostachya*, *Gnaphalium palustre*, *Plantago major*, *Polygonum persicaria*, and *P. punctatum*.

Coast Trail Pond (informal name) is the highest site in the study (230 m; Table 1). It occurs just southwest of Glenmire and northwest of Wildcat Lake. Little historical data exists on the history of grazing at this site, but its open nature and close proximity to the other sites suggests that that it would have been a prime site for cattle grazing early in the pre-settlement period. Today the site is nearly completely surrounded by coyote brush, though small patches of grassland (*Holcus lanatus*, *Bromus diandrus*), coffeeberry, yellow bush lupine (*Lupinus arboreus*), California blackberry and others also occur in the understory (Table 2). Stands of Douglas-fir occur within 100 m of the site (Fig. 5). Around the edge of the wetland are many grass species (*Lolium multiflorum*, *Vulpia bromoides*), sedges (*Carex*) and rushes (*Juncus effusus*), as well as *Rumex crispus*, *R. conglomeratus*, *R. acetosella*, *Plantago lanceolata* and many other species. *Phalaris arundinacea* dominates the wetland basin itself, with *Juncus effusus*, *Polygonum punctatum*, *Sparganium eurycarpum*, and *Cirsium vulgare*.

METHODS

Sediment cores were extracted from each site using a modified Livingstone sediment corer (Wright et al. 1984). We used a second corer with a plexiglass barrel (the short core) to retrieve the sediment-mudwater interface from Wildcat Lake. For coring at Wildcat Lake and Shutter Ridge Pond we used a coring platform – a 17-ft Cataraft outfitted with a plywood platform. For stability, the coring platform was anchored to the shore by ropes. The Glenmire core was taken in ca. 30 cm of water without a raft. The Coast Trail Pond and Creamery Bay Bog records were obtained by standing on the bog surface itself (Table 1).

Sediment stratigraphy was determined by splitting the Livingstone cores, noting the location of major stratigraphic and color changes. Magnetic susceptibility (Dearing 1999) of the sediments was measured with either a Bartington MS2E meter at 5-mm intervals, or a Sapphire II magnetic susceptibility meter. Magnetic susceptibility is the ability of the sediments to accept an induced magnetic charge. Often, sediments that have a higher inorganic content will have a higher magnetic susceptibility. This is because inorganic sediment often contains magnetic particles, such as magnetite, which readily accept the charge. These measurements can be used as a proxy for erosion within the watershed. In the case of lakes, high magnetic susceptibility from landscape erosion is most often a result of local disturbance, such as from a fire or human-caused land clearance, or from a climatic event.

Pollen analysis followed a modified Fægri and Iversen (1989) procedure. After addition of two *Lycopodium* tracer tablets for calculation of pollen concentration, usually 1 cc (5 cc for Wildcat Lake) of sediment was subjected to treatments of KOH for deflocculation and HCl to remove any carbonates, suspension in HF to dissolve silicates, and acetolysis to remove extraneous organics. Sample residues were stained, suspended in silicone oil, and examined at 400 - 1000 X using a light microscope, with comparison to the modern pollen reference collection at the Laboratory of Paleoecology (LOP) at NAU. Pollen was identified to the lowest taxonomic level, usually to genus. Pines (*Pinus*) and carrot family (Apiaceae) were differentiated into morphotypes. Sunflower family (Asteraceae) pollen was identified as sage and sagebrush (*Artemisia*), ragweed (*Ambrosia*), thistle (*Cirsium*), dandelion-type (cf. *Taraxacum*, Lactuceae), and Other Asteraceae. In the pollen diagrams, minor sage scrub species are often lumped together, and include *Cercocarpus*, *Rhus*, *Ribes*, *Garrya*, *Corylus*, *Eriogonum*, Polemoniaceae and Lamiaceae, among other species.

Fire history at all of the sites was determined by high resolution sedimentary charcoal analysis by close interval sediment sampling (see Whitlock and Anderson 2003). Sediment samples of 5-cc were taken from contiguous levels in each of the five core records. For the Glenmire, Coast Trail Pond, Creamery Bay Bog and Shutter Ridge Pond cores we sampled each 1-cm level down to the bottom of the core, producing 250, 482, 199, and 105 individual charcoal samples, respectively. For the much longer Wildcat Lake core, our sampling strategy was different. Samples of 5-cc were taken from a composite of contiguous 3-cm sections of the core. In this manner we sampled the entire core, or approximately 350 individual samples. Each sediment sample was placed in a beaker, and 10 ml of sodium hexametaphosphate was added. Sodium hexametaphosphate is a dispersant, which breaks down the sediments and releases the charcoal particles and other large organic fragments. Subsequently, 100 ml of distilled water was added to each sample. The resulting sediment mixture was gently stirred, then allowed to disaggregate for 48 to 72 hours. The slurry was then sieved through 125-µ and 250-µ mesh sieves. After washing with water, the sediments are scanned using a binocular dissecting microscope. Charcoal was identified and tallied by reference to particle color and texture. Most charcoal particles are shiny black, and often retain cellular structure. Charcoal influx (# of particles / cm^2 / yr) was calculated by multiplying the concentration (particles / cm^3) by the sediment accumulation rate (cm^2 / yr).

We analyzed the 125-μ and 250-μ fraction of charcoal particles because previous studies have shown that these two size fractions are probably indicative of local as well as extra-local and regional inputs of charcoal from fires (Whitlock & Anderson 2003). Several studies have shown that a greater proportion of charcoal particles > 125 microns are deposited close to a burn site (Whitlock & Millspaugh 1996; Gardner & Whitlock 2001). Therefore, distinct peaks in the charcoal especially of the larger size fraction could be interpreted as occurring primarily from a local fire. (This does not mean that other, smaller peaks in the 250-micron fraction are not local as well.)

Plant macrofossils from each record were isolated along with the charcoal fragments. All needle fragments, seeds and other fruiting bodies were identified under a binocular microscope using the reference collection at the LOP.

Chronologies for each core were developed by a variety of methodologies. For the upper portion of each record we assigned an age corresponding to the initiation of Euro-American settlement. The Spanish influence in this part of California commenced by 1817, with the establishment of the San Rafael Franciscan mission (Brown et al. 1999). After 1821, Point Reyes was opened to land claims, with the first granted in 1836 in the Olema Valley. The area was subsequently opened for grazing and dairy ranching (Livingston 1994, 1995). The settlement period was identified by increases in pollen indicators of grazing and land disturbance (i.e., dock [*Rumex*], plantain [*Plantago*], filaree [*Erodium*]). In addition, sediment sub-samples for ^{210}Pb and ^{137}Cs dating (Benoit & Rozan 2001), consisting of 5-cc each, were obtained for Coast Trail Pond and Creamery Bay Bog. These sediments were dried to constant weight in an oven. Three to five grams of the pulverized sediments were used in the gamma counting. Excess ^{210}Pb and fallout ^{137}Cs activities were measured non-destructively by gamma spectrometry using a high-resolution, low background well-type Ge detector (R. Ku, pers. comm., 2004). The excess ^{210}Pb was estimated from the difference in activities between ^{210}Pb and ^{214}Pb. ^{214}Pb was used to index the supported ^{210}Pb. The ^{137}Cs peak was identified at gamma energies centered at 661.6 keV.

Older portions of the cores were dated using the radiocarbon method, subcontracted to Beta Analytic, Inc. Radiocarbon ages were calibrated to calendar ages using CALIB 5.0 (Stuiver and Reimer 1993; Stuiver et al. 1998; see also http://calib.qub.ac.uk).

RESULTS

<u>Sediment Chronologies</u>

In addition to the two ^{210}Pb and ^{137}Cs profiles, fourteen radiocarbon dates were obtained for the five records (Table 3). Most samples were small enough to date by the AMS method, and generally consisted of small amounts of organic sediment, charcoal, wood fragments, or conifer needle fragments. Two samples contained enough carbon to return a whole-sediment standard radiocarbon date.

Construction of a sediment chronology began by assigning a 19th century age for the abrupt increase upcore of indicators of grazing (see above). According to historical records

(Livingston 1994), this horizon varied somewhat between sites (see Table 3). Additional dates were assigned from the ^{210}Pb and ^{137}Cs chronologies for Coast Trail Pond and Creamery Bay Bog. Ages for the lower parts of each record were fixed using calibrated ages for the radiocarbon (^{14}C) dates (Table 3). ^{14}C ages were in stratigraphic order for Wildcat Lake and Coast Trail Pond. However, a minor reversal in age was documented for Glenmire, while ages for Shutter Ridge Pond and Creamery Bay Bog presented greater problems.

For Shutter Ridge Pond, the age of 30 ± 40 yr BP at 84-85 cm (Beta-184997) was clearly too young and was not used in the chronology. However, for Creamery Bay Bog both of the ^{14}C ages were relatively old. I chose to use the older of the two dates (Beta-183871; 9010 ± 40 yr BP) for calculation of the sediment accumulation curve based on two factors. First, sea level reached its present position by ca. 7000 to 8000 years ago; this is consistent with the origination of this site near sea level. Second, an increase in Douglas-fir pollen occurs in this core at ca. 5000 cal BP, which is contemporaneous with a similar increase at Coast Trail Pond. It is possible that the other radiocarbon age is accurate instead, although evidence for that is not as substantial.

The resulting age-depth curves were based upon linear interpolation between radiometric and/or historic ages, or calculation of polynomials for specific sections of selected curves (Fig. 6; Table 4). A variety of curves was necessary, since deposition appeared to be non-constant for most records. Also, sediment accumulation rates increased substantially during the Historic period, necessitating separate calculations for that time period.

Below I examine the individual vegetation and fire histories for all five sites.

<u>Coast Trail Pond</u>

The Coast Trail Pond sequence is the longest record of those studied for this project, encompassing the last ca. 15,000 years. Major pollen changes occur at ca. 14,000, 10,500 and 6700 year ago, and at ca. 1850 AD. Up until ca. 10,500 years ago, major tree pollen types include *Abies*, *Pseudotsuga*, and *Pinus* (Fig. 7). Dominant upland shrub pollen includes members of the sunflower family (Asteraceae), fremontia (*Fremontodendron*) with California lilac (*Ceanothus*), while wood fern spores (*Dryopteris*) was also common. Wetland and aquatic species include members of the Apiaceae, meadow rue (*Thalictrum*), Poaceae, and water fern (*Azolla*). Magnetic susceptibility values (not shown here) are highest prior to ca. 14,000 years ago, while charcoal concentrations are highest centered around 13,200 years ago (Fig. 13), during the maximum occurrence of *Pseudotsuga* pollen.

During the early Holocene, from ca. 10,500 to 6700 years ago, virtually all of the previously dominant conifer and chaparral pollen types decline. Instead, dominant pollen includes *Alnus*, followed somewhat later by *Quercus* (by ca. 8500 years ago) (Fig. 7). Important shrubs include *Artemisia*, *Corylus*, followed after ca. 8500 by buckwheat (*Eriogonum*), manzanita (Ericaceae), mountain-mahogany (*Cercocarpus*) and members of the sunflower family. Wetland pollen types include cattail (*Typha*) and sedge (Cyperaceae), while wood fern spores and pollen of meadow rue become less common. Magnetic susceptibility values remain low. Charcoal concentrations increase during this period, with a second more substantial increase after ca. 8500 years ago (Fig. 13).

After ca. 6700 years ago, major tree pollen includes oak, alder and tanoak (*Lithocarpus*), with increasing amounts of *Sequoia* and *Pseudotsuga* (especially after ca. 4500 years ago). Chaparral and sage scrub pollen, including *Artemisia*, *Ceanothus*, *Cercocarpus*, *Eriogonum*, Ericaceae and Asteraceae, while hazel continues in importance (Fig. 7), as does grass. Plants more characteristic of standing water are common, including the algae *Botryococcus*, water fern, water lily (*Nuphar*), and pondweed (*Potamogeton*), as well as wetland plants (Apiaceae and *Salix*). Magnetic susceptibility levels remain moderate. Charcoal influx is high during this period (Fig. 13), with maximum influx associated with dominance of sage scrub but increasing coast redwood and Douglas-fir.

Based on Livingston (1994) the historic period is dated to 1850 AD. Major pollen changes include establishment of non-native herbs characteristic of pasturage, including *Rumex*, *Plantago*, *Erodium*, and probably dandelion (*Taraxacum* = Lactuceae). Other indicators of landscape disturbance include pollen of goosefoot family (Chenopodiaceae = Cheno-Am). Direct evidence of presence of ungulates includes the occurrence of the dung fungus, *Sporormiella*, in these sediments. Significantly, magnetic susceptibility increases during the historic period, while charcoal concentration values drop to near-zero.

<ins>*Summary*</ins>: These pollen changes are consistent with Late Pleistocene conversion of forest with patches of chaparral to generally non-forested vegetation – chaparral and sage scrub – for the remainder of the Holocene. In general, perennial water existed at the site until ca. 10,500, and after ca. 6700 years ago. Drier conditions generally without perennial water occurred from 10,500 to 6700 years ago. Periods of higher charcoal concentration, presumably of greater fire occurrence, include during the late Pleistocene when Douglas-fir and pine were abundant, and during the Holocene when chaparral and sage scrub vegetation prevailed, but with increasing coast redwood and Douglas-fir regionally. Changes during the Historic period are unprecedented, and are detailed below.

<ins>Glenmire</ins>

The Glenmire record is the second oldest sequence in this project. Pollen preservation is very good back to about 6200 years ago, but pollen is essentially absent in early Holocene sediments. Magnetic susceptibility values for the early Holocene sediments are very high, suggesting intense erosion into the basin or intense decomposition. This alone may account for the lack of pollen during that time period.

However, the pollen record of the middle and late Holocene is dominated by *Sequoia*, *Pseudotsuga*, *Quercus*, *Lithocarpus* and *Alnus* from ca. 6200 to historic times (Fig. 9). Although *Artemisia* and *Corylus* pollen is also abundant throughout the period, other chaparral and sage scrub pollen do not increase until after ca. 1600 years ago. These include *Eriogonum*, members of the sunflower (Asteraceae), legume (Fabaceae), waterleaf (Hydrophyllaceae), pink (Caryophyllaceae), goosefoot (Chenopodiaceae), and phlox (Polemoniaceae) families, along with meadow rue (*Thalictrum*). The wetland pollen and spore taxa are dominated by members of the grass (Poaceae), sedge (Cyperaceae), and carrot (Apiaceae) families, and by ferns. Water levels may have been considerably lower for a period from ca. 1600 to 800 years ago, when cattail (*Typha latifolia*) and Apiaceae predominated, and may have been higher just before Euro-American settlement, when pondweed (*Potamogeton*) was abundant.

Major pollen changes document the Historic period, the beginnings of which are a little obscure for the Glenmire area. Though part of the Shafter properties, Livingston (1994) found reference to habitation and grazing there by the 1880's, which date we use as a settlement horizon. Pollen of the exotic tree *Eucalyptus* is recovered from this period. Increases in pollen of *Erodium*, thistle (*Cirsium*), *Rumex* and mustard family (Brassicaceae) are consistent with other sites in the area, and indicate the effects of land disturbance and grazing. Affected trees in the area were most certainly *Sequoia* and *Pseudotsuga*, whose pollen shows a marked decline during the Historic period. (A few grains of both *Erodium* and *Eucalyptus* were recovered from older sediments – Fig. 8 – which may suggest our chronology is slightly in error or redeposition of materials occurred then). Magnetic susceptibility shows an increase during the Historic period as well, probably as a result of grazing and logging. In the most recent decades, both *Pseudotsuga* and *Pinus* pollen increases, suggesting a recovery of these species locally, while *Sequoia* has not recovered.

The charcoal influx record shows little charcoal deposited in sediments before ca. 5300 years ago (Fig. 13). Moderate amounts were deposited from ca. 5300 to 3200 years ago, with much greater amounts after that. Charcoal is found in sediments deposited during the Historic period – perhaps as a result of re-deposition from earlier times.

<u>Summary</u>: These pollen and other changes suggest that the Glenmire basin was dry enough in the early Holocene that organic sediments were not preserved. Groundwater tables apparently rose after ca. 6200 years ago, allowing for preservation of the pollen record. During the middle and late Holocene the site was surrounded by a mixed conifer – hardwood forest, not unlike that which occurs there today. The small mire probably underwent multiple drying and wetting episodes during the late Holocene, as witnessed by periodic successions of wetland plants there. Effects of Euro-American influence on the landscape are shown by declines in major tree species and increases in disturbance indicators.

<u>Wildcat Lake</u>

The Wildcat Lake record documents vegetation and fire histories of the coastal sage scrub over the last ca. 3200 years. This lake has had an extremely high sediment accumulation rate (SAR), depositing almost 11 m of sediment over this period. In my experience this is very unusual, and Wildcat Lake appears to be a very productive lake for its size.

Wildcat Lake originated from a coastal landslide (Clague 1969), and the bottommost sediments of the core consisted of a compacted peat with high magnetic susceptibility, which was probably deposited in the depression formed immediately after the slump. Above this is a silty peat to about 8 m depth in the profile, transitioning to organic sediments (gyttja) for the upper 8 m of sediment.

The earliest pollen assemblages, from the core bottom (3200 years ago) to ca. 2500 years ago are dominated by *Alnus* pollen (Fig. 9). This probably represents initial colonization of the site by alder. Other important tree pollen types are *Sequoia*, *Pseudotsuga*, and *Quercus*, with smaller amounts of *Pinus* and *Lithocarpus*. After 2500 years ago, *Alnus* declines, but the other tree species remain important. Pollen of coastal sage scrub species is abundant throughout the record, including *Ceanothus*, *Artemisia*, members of the sunflower family (Asteraceae) and others (*Cercocarpus*, *Rhus*, *Ribes*, *Garrya*, *Corylus*, *Eriogonum*, Polemoniaceae and Lamiaceae – Other Sage Scrub Species on Fig. 9).

Of the wetland pollen flora, initially *Typha latifolia* and sedges colonized the small basin (Fig. 9). However, after the decline in *Alnus*, *Myrica* and *Salix* pollen became important, probably growing on the lake shore. Pollen of water-milfoil (*Myriphyllum*) and spores of *Botryococcus* indicate a diverse aquatic flora in a shallow lake. The planktonic algae *Pediastrum* increases by about 1000 years ago, and contemporaneous declines in wax myrtle and willow suggest an increase in lake level for at least several hundred years.

The Historic period, here determined to commence by about 1850 AD (Livingston 1994) documents pollen changes similar to Glenmire and Coast Trail Pond. Probably associated with land disturbance and grazing, increases in *Plantago*, *Rumex*, *Erodium*, and *Cirsium* occur. Two non-local trees, *Eucalyptus* and walnut (*Juglans*), also occur during this time. These changes are associated with a decline in *Sequoia*, but an increase in *Pseudotsuga*.

Charcoal influx (Fig. 13) show considerable fluctuation in deposition. Evidently, fire was common around Wildcat Lake throughout the last 3200 years. However, charcoal influx declines during the Historic period.

Summary: The record from Wildcat Lake documents the last 3200 years of vegetation change and fire history from a coastal location. Contributions of pollen from coastal sage scrub species suggests that vegetation type grew around the lake throughout much of the late Holocene, as it does today. However, the abundance of mixed conifer – hardwood pollen types, especially coast redwood, suggests that Wildcat Lake must have been near the forest border, again much like it is today. Fire has been a factor of disturbance around the lake, predominantly during the pre-historic period. The effects of land clearance (loss of coast redwood) and disturbance (numerous exotic herbs) are noted, beginning in the 1850's, when the Shafter ranch used the site for cattle grazing (Livingston 1994).

Shutter Ridge Pond

The Shutter Ridge Pond record is the shortest in the series, spanning the last ca. 2200 years (Fig. 10). For most of the record – from the earliest sediments until the Historic period – the pollen assemblage is a mixture of conifers and hardwoods, coastal sage scrub species and grasses. Grass pollen dominates the pre-settlement record. Abundant tree pollen types include *Sequoia*, *Pseudotsuga*, *Lithocarpus* and probably *Alnus rubra*. Sage scrub and chaparral plants (i.e., *Ceanothus*, *Cercocarpus*, *Artemisia*, Brassicaceae, *Eriogonum*, *Rhus* and *Polemonium*) are important pollen types, along with members of the sunflower family (Asteraceae). As for wetland pollen and spores, dominants include sedge (Cyperaceae), ferns, and buttercup (*Ranunculus*). The occurrence of quillwort (*Isoetes*) suggests perennial water in the basin during this time.

The Shutter Ridge Pond area was among the first to be settled by Euro-Americans, sometime in the 1840's (Livingston 1994). As with all other records in this study, the pollen assemblage during the Historic period is dominated by introduced herbs, including *Plantago*, *Erodium*, and *Rumex*, and the predominance of introduced annual grasses in the vicinity also shows up in the pollen record (Fig. 10). Wetland indicators decline, except for *Typha*, as do many trees (i.e., *Sequoia*, *Pseudotsuga*, *Lithocarpus* and *Alnus*). Today, *A. rubra* is confined to stream banks immediately east of the site (Fig. 2).

Changes in the charcoal concentration parallel the pollen data. Higher charcoal abundances occur during pre-settlement times, with lower abundances during the settlement (Fig. 13).

Summary: Although the shortest in this study, the late Holocene Shutter Ridge Pond record is similar to others at Point Reyes. Pollen data suggest pre-settlement grassland surrounded the pond, with patches of mixed conifer and hardwood, as well as coastal sage scrub, nearby. With local settlement and grazing came declines in both forest and shrub components. This was especially true for red alder, which is confined today to riparian locations in the vicinity of the Pond. Indicators of grazing and land disturbance are abundant; increases in grass pollen are probably a result of introduced annual grasses there. Fire appears to have been more frequent or abundant in the pre-settlement period, while of considerably lesser importance in the 150 years. Local water tables may have declined over the last 150 years as well, as shown by a decline in perennial aquatic plants.

Creamery Bay Bog

The Creamery Bay Bog site is located near sea level (ca. 6 m) and is the site farthest to the west in our study. It is located on the "F" Ranch – one of the earliest ranches on the Peninsula – with the first ranch house built as early as 1842 or 1843 (Livingston 1994). The ca. 1.25 m record probably encompasses much of the Holocene (Table 3), but pollen only preserved in the top 1.0 m, or the last 8000 years.

Pollen in sediments deposited prior to ca. 5500 years ago is dominated by fern spores, Poaceae, and members of the sunflower family (Asteraceae) (Fig. 11). Minor amounts of *Pinus*, *Quercus* and *Alnus* were recovered. This is suggestive of dry meadow conditions. However, between ca. 5500 years ago and the time of Historic settlement, the pollen assemblages are dominated by members of the sunflower family, grasses and sage scrub flora (including the same species as listed at Coast Trail and Shutter Ridge Ponds – see above). Small amounts of pollen of pine is recovered, along with *Sequoia*, *Pseudotsuga*, and *Quercus* appear during this time. The percentages of the latter three types are so low that they preclude local occurrence of those trees there. The abundance of quillwort (*Isoetes*) spores and of pollen of *Ranunculus* from ca. 5500 to at least 1000 years ago suggests wet meadow conditions, with perhaps some standing water at times.

The Historic period is dated to about 1840 AD, and pollen of introduced species is common beginning then. This includes *Rumex, Plantago*, *Erodium*, cf. dandelion (*Taraxacum*, Lactuceae). A single pollen grain of corn (*Zea mays*) was recovered early in this period, while pollen of the introduced tree *Eucalyptus* was recovered late in the profile. (Fig. 11). Pine pollen declines in this time period.

Besides a large influx of charcoal, dated to ca. 10,200 years ago, charcoal is consistently present, but in low concentrations, prior to the Historic period (Fig. 13).

Summary: The bottom radiocarbon date suggests that sediments were being deposited at this site for much of the Holocene. However, conditions were unfit for pollen preservation until about 8000 years ago. Dry meadow conditions existed from ca. 8000 to 5500 years ago, when water tables were apparently lower than today. This may reflect climate, or it may be partly a result of local sea level history, as sea level did not reach its present position until ca. 7000 years ago, raising the local baseline and water table at the same time. Stabilization of sea level or climate change probably allowed for wet meadow conditions to form by ca. 5500 years ago. The pollen record strongly suggests that vegetation during most of the Holocene was grassland, with stands of coastal sage scrub on uplands nearby. The pollen also suggests that mixed conifer – hardwood forest was not present at the site. The low but consistent levels of charcoal in this record are also consistent with grassland vegetation, not forest.

DISCUSSION

Holocene Vegetation Change on Point Reyes

The story of vegetation change on the Point Reyes peninsula has been explored by Russell (1983), Rypins et al. (1989), and Duncan (1992). Rypins et al. (1989) examined sediments spanning the Pleistocene – Holocene transition, when the dominant Douglas-fir – pine – fir forest transitioned to coastal sage scrub and grassland during the Holocene. Both Russell (1983) and Duncan (1992) examined late Holocene sites on the Peninsula. Russell's work at Wildcat Lake, although undated, showed that sage scrub vegetation and grassland varied in importance during the last ca. 1000 years, prior to Euro-American settlement. Duncan's dissertation included pollen analysis from Mud Pond, which also included vegetation changes over the last ca. 1000 years. Pre-settlement vegetation was typically mixed conifer and hardwood forest.

Our work on five sites within PORE provides greater detail on vegetation changes on the Peninsula by examining sites within present coastal grassland, woodland, coastal sage scrub and mixed conifer forests to provide an integrated picture of vegetation and climate over the last ca. 15,000 years. The five sites are of varying lengths, but the longest records show patterns consistent with a dry Early Holocene and wetter Late Holocene.

Our analysis of a new Coast Trail Pond sediment core confirms the conclusions of Rypins et al. (1989) on the nature of late Pleistocene forests of Point Reyes. During this time period sea level was ca. 100 m lower in elevation, and further west due to greater amounts of ice in land-based glaciers. The higher apparent elevation, more inland location, and cooler sea surface temperatures during the late Pleistocene fostered a Douglas-fir – pine – fir forest with moist understory elements to exist here, while Coast Trail Pond itself was probably perennially wet. Evidence for an expanded pine forest in the region also comes from marine cores (Barron et al. 2003). Evidence for cooler sea surfaces in the Pacific during this time comes from plankton foraminifers and alkenone stratigraphies in offshore marine cores. For example, sea surface temperatures in northern California and southern Oregon were ca. 2 – 5 °C cooler than today (Doose et al. 1997; Ortiz et al. 1997; Mix et al. 1999; also see Barron et al. 2003). Cooler temperatures probably signify a stronger California Current, which today brings cool water to California from the North Pacific. Paleoclimatic reconstructions (COHMAP 1988; Mock and Bartlein 1995; Bartlein et al. 1998; Kutzbach et al. 1998) document greater penetration of Pacific stormtracks to the south during winter as the Jet Stream was diverted to more southerly latitudes by the height of the Laurentide Ice Sheet in the North American interior. At the Coast Trail Pond site, closed conifer forest lasted until ca. 10,500 calendar years ago (Fig. 12).

After ca. 10,500 years ago, however, warming climate conditions and rising sea levels (COHMAP 1988) accompanied vegetation change at Coast Trail Pond, which became an open hardwood forest with a large sage scrub component. Pollen evidence suggests that coyote brush dominated there, as it does today. Sedimentary evidence also suggests considerably drier conditions, with pollen indicators suggesting a wetland, not a perennial pond, existed at the Coast Trail Pond site. These conditions persisted until at least 6700 years ago, and probably represent the most persistently dry section of the present interglacial at Point Reyes.

Supporting evidence for dry conditions during the early Holocene is found at Glenmire and Creamery Bay Bog. At Glenmire, sedimentation began by 8000 years ago, but no pollen or other organic remains were preserved in the sediments until about 6200 years ago (Fig. 12), when water tables apparently rose in the basin, encouraging development of a sedge wetland. Dry conditions persisted at Creamery Bay Bog, situated near present-day sea level, until after 8000 years ago, shown by sandy sediment and a lack of pollen preservation. For the next ca. 2500 years, until 5500 years ago, the site was a dry grassland with ferns.

These interpretations are supported by paleoclimatic models (Bartlein et al. 1998; Kutzbach et al. 1998) that demonstrate higher summer solar insolation than today during the early Holocene in the Northern Hemisphere. This may have contributed to higher sea surface temperatures (Barron et al. 2003), and an intensification of Mediterranean conditions along the California coast and inland, with lowered groundwater tables and drying of perennial wetlands (Anderson and Smith 1994).

After the dry early and middle Holocene, changes in the wetland flora indicate that water tables generally rose at the Point Reyes sites. Specific changes were individual to each record, however. Besides the aforementioned development of a sedge wetland at Glenmire after 6200 years ago, perennial water returned to Coast Trail Pond, as shown by the reoccurrence of water fern (*Azolla*), and the establishment of water lily (*Nuphar*) there. Perennial water also was found at Creamery Bay Bog, with the establishment of the aquatic quillwort (*Isoetes*) at that location. These changes were accompanied by development of sage scrub, and by increases in coast redwood regionally (Barron et al. 2003). Sage scrub mixed with mixed hardwoods developed at Coast Trail Pond, persisting until ca. 4500 years ago (Fig. 12), by which time Douglas-fir increased in abundance there. Mixed conifer and hardwood forest with patches of coyote brush were found at Glenmire. Grassland with sage scrub developed at Creamery Bay Bog.

All five records include data for the late Holocene. Establishment of Wildcat Lake was caused by a large landslide (Clague 1969), and the developing wetland was then originally colonized by alder. However, coastal sage scrub with grassland and coast redwood forest soon dominated the region around the lake, persisting until the Historic period (Fig. 12). Water tables rose in the vicinity of Shutter Ridge Pond by ca. 2200 years ago, and record the local vegetation as grassland with sage scrub with hardwood woodland for the last two millennia. Coast redwood apparently increased in abundance at the higher elevation sites – Coast Trail Pond and Glenmire – by about 1500 years ago, also accompanied by Douglas-fir at Glenmire. These vegetation associations persisted largely in similar form at these sites for the remainder of the Holocene, until the Historic period (or Anthropocene). Wetter conditions are recorded for several hundred years between ca. 1000 and 500 years ago at both Wildcat Lake and Glenmire.

The Historic Period (Anthropocene)

Changes on Earth's landscape during the last several centuries have been sweeping, and have led some to suggest that we have entered a new geologic time period – the Anthropocene – in which the dominant agent of ecosystem disturbance is no longer a physical force, but the human species itself (Crutzen 2002; Crutzen and Steffen 2003; Ruddiman 2003). Human activities have led to biological invasions in virtually all ecosystems worldwide (Vitousek et al. 1996), and have been particularly well-documented over the last few centuries for eastern North America (see for example Russell et al. 1993). For the Point Reyes Peninsula, changes in vegetation over the last century and a half have been dramatic, fostered by the settlement of Euro-Americans after ca. 1840 AD. The pollen record documents introduction of non-native species, both herbaceous and arboreal, as well as diminishment of other species due to forest clearance for timber.

Non-native herbaceous species were introduced into southern California as early as the 18th century with the cattle ranching practices of the early Spanish hacienda and mission system. Mensing and Byrne (1998) documented the occurrence of *Erodium cicutarium*, an introduced species from Eurasia, in southern California from sediments of the Santa Barbara Basin by 1760 AD. It was well-established near present Stockton in the Central Valley of California and in eastern Washington by 1844, and on islands within Great Salt Lake, Utah, by 1850 (see references in Mensing and Byrne, 1998). *Erodium* must have arrived on the Peninsula at about the same time, in association with other exotic pollen types such as *Rumex*, *Plantago* and dandelion (cf. *Taraxacum*). Each of the five sites shows a distinct increase in these species in the upper portion of the core. It is likely that these species were spread after settlement by Euro-American ranchers in the middle of the 19th century. Livingston (1994) suggests the Creamery Bay Bog and Shutter Ridge Pond areas may have been grazed as early as the 1840's, Wildcat Lake and Coast Trail Pond by the 1850's, and Glenmire certainly by 1880 AD. This time period is also fixed by the occurrence of *Eucalyptus* pollen at several sites – *Eucalyptus* trees were often planted on the Peninsula for wood and windbreak, as early as the 1870's (Johnson 1971; Livingston 1994).

Erosion rates into the wetlands appear to have increased at three of the sites as well during the Historic period, probably as a result of land clearance and disturbance. Magnetic susceptibility increased during the Historic period at Shutter Ridge Pond, Glenmire and Coast Trail Pond (not shown). This increase at Coast Trail Pond is associated with the occurrence of *Sporormiella* spores – a dung fungus usually associated with herbivores, such as cattle (Davis et al. 1977).

Increases in exotic species pollen percentages come at the expense of native species populations. For instance, the pollen records of Coast Trail Pond, Shutter Ridge Pond, Glenmire and Creamery Bay Bog all document declines in coastal sage scrub or chaparral species during the Historic period. In one case – Glenmire – coyote brush appears to rebound during the last decades. Similarly, the effects of logging appear in four of the records. The decline of Douglas-fir is widespread (Shutter Ridge Pond, Glenmire, Wildcat Lake and Creamery Bay Bog), though at Glenmire, Douglas-fir increases in the last few decades. This was also noted in stand-age data (Brown et al. 1999). Similarly, coast redwood declines at Shutter Ridge Pond, and the decline is particularly severe in the Wildcat Lake pollen record. Pine declines at the Creamery Bay Bog site.

Declines in Douglas-fir and coast redwood are probably a result of local logging which commenced shortly after Euro-American settlement. Toogood (1980) reported that lumbering of redwood stands occurred in the Olema Valley and on Bolinas Ridge from 1849 to 1858. A maximum of four lumber mills were in operation in that area during that time (Brown et al. 1999). It seems reasonable to assume that other small operations operated in much the same manner during the mid-19th century.

Fire History

Analysis of charcoal in sediments has become increasingly important for understanding the long-term history of fire disturbance in forested ecosystems (e.g., Millspaugh & Whitlock 1995; Whitlock & Millspaugh 1996; Anderson & Smith 1997; Long et al. 1998; Hallett & Walker 2000; Mohr et al. 2000; Brunelle & Anderson 2003). However, such studies are rare in non-forested areas (Brown et al. 2005). Our analysis of sites both within forest, sage scrub and grassland in Point Reyes National Seashore is a unique endeavor. Examination of these fire histories allows us to compare the relative rates of occurrence and importance of fire in adjacent, but physiognomically different, plant communities.

Critical to our understanding of the centennial and millennial-scale fire history is the history of fire over the last two centuries. Little was known about the pre-Historic fire regimes on the Point Reyes Peninsula until the work of Finney (1990) and Brown et al. (1999). In the Brown et al. study, using two Douglas-fir and one coast redwood stands, the Limatour Road and Five Brooks sites showed periodic fire from the beginning of the record in the 18th century until ca. 1905 (Five Brooks) or 1918 AD (Limatour Road). The records from the Pine Grove Redwoods exhibited multiple fire scars to 1945 AD. Mean Fire Intervals (MFI) for all stands from the early 1800's to ca. 1900 AD was 7.7 to 8.5 years – characteristic of a surface fire regime on the Peninsula. Finney (1990) examined fire scars on coast redwood trees of Bolinas Ridge and the Kent Lake region, and found pre-settlement MFI 7.5 years for small fires, and < 2 years for larger fires. The MFI during the last half of the 20th century was an order of magnitude longer. Near Point Reyes, Jacobs et al. (1985) reported MFI of 20-30 years since the 1850's, while Finney and Martin (1990) documented pre-settlement MFI's from Annadel State Park of < 10 years. Finney (1990) and Brown et al. (1999) believed that the change in fire regime in the 20th century was a direct result of cessation of the surface fire regime that probably existed during the pre-Historic period.

For the longer record of fire, charcoal influx (# of particles / cm^2 / yr) was plotted on a logarithmic scale for ease of comparison (Fig. 13). As with the pollen record, Coast Trail Pond has the longest history of fire, while Creamery Bay Bog and Glenmire include much of the Holocene. The Wildcat Lake and Shutter Ridge Pond records only include the late Holocene. Each site records abundant charcoal at nearly every level in the core (only at Creamery Bay Bog is charcoal absent in some levels), suggesting fires were regularly occurring agents of disturbance during the entire Holocene at all sites. However, the time between sedimentary charcoal samples (Wildcat Lake, 10 yrs; Glenmire, 30 yrs; Coast Trail Pond, 33 yrs; Shutter Ridge Pond and Creamery Bay Bog, 87 yrs) does not allow us to distinguish individual fires, or reconstruct MFI's. Here we use the variations in charcoal influx rates to generally suggest more or less frequent occurrence of fire.

Charcoal influx during late Pleistocene time was relatively low, probably as a result of moist forested conditions then. However, late Pleistocene charcoal influx is highest at ca. 13,000 years ago when Douglas-fir dominated forests around Coast Trail Pond (Fig. 7). Charcoal influx increased at the opening of the Holocene at both Coast Trail Pond and Creamery Bay Bog, as an open sage scrub (Coast Trail Pond) or grassland (Creamery Bay Bog) vegetation developed there. Fire occurrence reached its maximum during the early Holocene at Coast Trail Pond (ca. 8500 to 7000 years ago) when pollen evidence suggests the driest conditions of the post-glacial (Fig. 12).

After ca. 7000 years ago, the inferred characteristics of fire differed for each of the records. Charcoal influx (and fire occurrence) declined at Coast Trail Pond as mixed hardwoods grew locally with sage scrub. At the same time, fire occurrence probably increased at the Glenmire site, with the increasing importance of conifers such as coast redwood and Douglas-fir there. At the dry grassland site – Creamery Bay Bog – fire occurrence remained essentially the same through the middle Holocene. In fact, at all three sites, these relationships continued through the middle Holocene, and into the late Holocene, suggesting that local controls – perhaps vegetation development – predominated over broader-scale climatic controls during this period.

However, late Holocene charcoal sequences show an increasing importance of fire at Glenmire (by 3500 years ago), Coast Trail Pond (after ca. 2500 years ago) and Shutter Ridge Pond (particularly after ca. 2000 years ago) (Fig. 13), while the Wildcat Lake record shows abundant charcoal throughout the late Holocene record. These trends, occurring at sites with very different vegetation types, suggest that a factor other than local vegetation development was probably controlling fire occurrence during the late Holocene. The lone exception, Creamery Bay Bog, shows a decline in fire importance after ca. 4000 years ago, coincidental with development of moist meadow conditions there, which may have actually inhibited burning of the bog.

What might be the cause of the nearly synchronous increase in the importance of fire during the late Holocene? The reason for this is not clear, but may be related to either climate changes or the effect of coastal Native American groups. Local climate changes related to sea-level rise can probably be ruled out since sea levels approached their near-modern extent by ca. 6000 yr BP (Atwater et al. 1977; Moratto 1984). The pollen data document a change to generally wetter climate during the late Holocene, with increased groundwater tables contributing to more persistent wetlands or higher lake levels. Wetter climates may have fostered additional vegetation growth, which could have burned more frequently during the summer dry season.

Alternatively, human activities during the late Holocene may have contributed to higher fire frequencies. Anthropogenic burning by Native populations at the time of European contact is well-documented (Timbrook et al. 1982), although the degree to which Native Americans may have altered vegetation distributions is the subject of considerable debate (Vale 1998, 2000; Keeley 2002). Human habitation of the Point Reyes Peninsula by coastal Miwok may have begun by at least 5000 years ago (Treganza 1961; Duncan 1992). The number of radiocarbon dates on archaeological sites on and near Point Reyes increase substantially after ca. 3500 years ago (Moratto 1984, p. 275; Duncan 1992), suggesting an expanding human population then. Working primarily in the central and south coastal areas, Keeley (2002) argued that lightning is infrequent enough to account for the high fire frequencies that occurred in the pre-Historic period. In the absence of human-caused fire, the natural fire rotation of coastal shrublands such as chaparral might be 10^1 to 10^2 years (Bendix 2002). Keeley (2002) hypothesized that large coastal populations during the late Holocene greatly accelerated the natural fire frequency in shrubland dominated ecosystems. Due to their innate weak resilience to fire frequencies of > once or twice a decade, this often has resulted in the conversion of shrublands to grasslands.

The paleoecologic record from Point Reyes may provide a partial test of this hypothesis. If human burning was an important factor during the late Holocene, we would expect to see periods of elevated grass pollen at the expense of coastal sage scrub in the paleobotanic records. During the late Holocene, when coastal sage scrub was at its maximum development, grasslands must also have been widespread near all sites (Figs. 7 – 11). At Wildcat Lake, however, grass pollen clearly increases over the last 1000 years. Russell (1983) also noted that changes in proportions of grass to shrub indicated varying fluctuations in grassland and shrubland there. The co-occurrence of high grass and shrublands from these coastal sites is supportive of Keeley's hypothesis, but not conclusive. Higher temporal resolution of pollen data may be necessary to answer this question. In any event, the data are not inconsistent with the suggestion that Native Americans may have played a substantial role in management of these plant communities through the use of fire.

Though never reaching zero, charcoal influx declines during the Historic period at three of the five sites – Coast Trail Pond, Wildcat Lake and Shutter Ridge Pond (Fig. 8). Charcoal influx does not decline noticeably at Glenmire or Creamery Bay Bog. Based on the work of Finney (1990) and Brown et al. (1999) we would expect charcoal delivery to the sediments of these sites to cease by the early or middle 20th century. It is likely that some or all of the charcoal in sediments deposited during the 20th century is re-deposited from earlier fires, remobilized by the higher erosion rates of basins during the Historic period. If so, we would expect deposition of charcoal to continue to decline in these basins into the future, until some time when the inevitable next fire burns the vegetation in the drainage basin.

CONCLUSIONS

The charcoal and pollen data from the Point Reyes sites suggest a complex relationship between vegetation type, climate, human settlement history and fire occurrence. For instance, each vegetation types produced abundant sedimentary charcoal, but conifer forest and sage scrub produced greater amounts of charcoal in general than did grassland during the Holocene. Climate affects the characteristics of each sedimentary basin – determining whether that basin will be perennially wet or periodically dry. These local conditions, in turn, affect the local vegetation at each site. Human activities can have a potentially large effect on both vegetation and fire history. The most rapid, widespread vegetation change at all sites occurred during the Historic period, when exotic species were introduced to the landscape as a result of human activities such as cattle grazing. Yet human activities may have had entirely different effects on the fire regime at different times in the past, with Native American populations potentially contributing to high fire frequencies, and Euro-Americans causing fire to become more rare, but perhaps more destructive.

Each of these factors has been important in determining the characteristics of the vegetation and fire disturbance histories of Point Reyes. In times of increasing human impact on the landscape and on our climate, retrospective studies such as these become important in understanding how modern vegetation communities came to be as they are today. These studies also serve as a reference towards which restoration of former habitats can be accomplished, or as a baseline to determine the magnitude of future impact of humans.

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LIST OF TABLES

Table 1. Location and coring information for each of the five study sites

Table 2. List of plants identified near the study sites.

Table 3. Radiometeric ages for the five study sites.

Table 4. Linear and Polynomial Curves used to calculate Sediment Accumulation Rates.

LIST OF FIGURES

Figure 1. Vegetation associations around and near the Creamery Bay Bog study site.

Figure 2. Vegetation associations around and near the Shutter Ridge Pond study site.

Figure 3. Vegetation associations around and near the Wildcat Lake study site.

Figure 4. Vegetation associations around and near the Glenmire study site.

Figure 5. Vegetation associations around and near the Coast Trail Pond study site.

Figure 6. Sediment Accumulation Rate (SAR) curves for the five records. Due to variations with depth, SAR's are calculated for different segments of the record for (a) Creamery Bay Bog; (b) Shutter Ridge Pond; (c) Wildcat Lake; (d) Glenmire; (e) Coast Trail Pond.

Figure 7. Pollen and spore percentages of the Coast Trail Pond sediment record. HP = Historic Period; L = Late; M = Middle; E = Early; Holo = Holocene; Pleisto = Pleistocene.

Figure 8. Pollen and spore percentages of the Glenmire sediment record. Abbreviations as in Fig. 7.

Figure 9. Pollen and spore percentages of the Wildcat Lake sediment record. Abbreviations as in Fig. 7.

Figure 10. Pollen and spore percentages of the Shutter Ridge sediment record. Abbreviations as in Fig. 7.

Figure 11. Pollen and spore percentages of the Creamery Bay Bog sediment record. Abbreviations as in Fig. 7.

Figure 12. Summary of major vegetation changes at Point Reyes over the last 15,000 years.

Figure 13. Charcoal accumulation rates (# of particles / cm^2 / year) for the five Point Reyes sites.

TABLE 1. Location and coring information for study sites

Site	Elevation (m)	Latitude, Longitude	USGS Quadrangle	Date Cored	Coring Depth (m of H_2O)
Creamery Bay Bog[1]	6	37° 04’30” 122° 57’15”	Drakes Bay	20 May 2002	Bog Surface
Shutter Ridge Pond[1]	35	38° 02’54” 122° 47’55”	Inverness	19 May 2002	0.85
Wildcat Lake	62	37° 58’10” 122° 47’05”	Double Point	30-31 October 1998	8.65
Glenmire[1]	167	37° 59’30” 122° 47’20”	Double Point	1 November 1998	0.30
Coast Trail Pond[1]	230	37° 59’07” 122° 48’00”	Double Point	21 May 2002	Bog Surface

[1] Informal name

TABLE 2. Plants identified by NPS personnel in October 2004 at and near the Five Study Sites.

	Species	**Coast Trail Pond**	**Glenmire**	**Wildcat Lake**	**Shutter Ridge Pond**	**Creamery Bay Bog**
Trees	*Eucalyptus globulus*			X		
	Pinus radiata			X		
	Pseudotsuga menziesii	X	X	X		
	Umbellularia californica	X		X		
Shrubs	*Artemisia californica*			X		
	Baccharis pilularis	X	X	X	X	X
	Corylus cornuta		X			
	Holodiscus discolor		X	X		
	Lonicera hispidula		X	X		
	Lupinus arboreus	X		X		
	Myrica californica					X
	Rhamnus californicus	X	X	X		
	Ribes sp.					X
	Rubus parviflorus		X			
	Rubus spectabilis					X
	Rubus ursinus	X	X	X		X
	Salix lasiolepis			X		
	Sambucus racemosa			X		
	Toxicodendron diversilobum	X	X	X		
Herbs	*Achillea millifolium*	X		X		X
	Anthemis cotula				X	
	Artemisia douglasiana			X		
	Athyrium filix-femina			X		
	Calystegia purpurata ssp. *purpurata*			X	X	
	Carduus pycnocephalus	X			X	
	Cirsium vulgare	X	X	X	X	
	Claytonia siberica					X
	Conyza canadensis	X				

	Crocosmia crocosmiiflora			X		
	Dryopteris sp.					X
	Epilobium sp.					X
	Erechtites glomerata			X		
	Erechtites minima	X	X			X
	Eriophyllum staechadifolium			X		
	Erigeron glaucus			X		
	Eschscholzia californica			X	X	
	Fragaria vesca			X		
	Galium trifidum var. *Pacificum*					X
	Geranium dissectum	X				
	Gnaphalium sp.	X			X	
	Gnaphalium palustre		X		X	
	Gnaphalium purpureum					X
	Heracleum lanatum	X	X	X		
	Heterotheca villosa				X	
	Hypochaeris radicata	X		X	X	
	Lathyrus sp.			X		
	Lessingia filaginifolia				X	
	Linum bienne				X	
	Lotus scoparius			X		
	Madia sativa	X	X		X	
	Marah fabaceus			X		
	Mentha pulegium				X	
	Mimulus aurantiacus			X		
	Monardella villosa				X	
	Myosotis sp.			X		
	Navarretia squarrosa	X			X	
	Pentagramma triangularis			X		
	Plantago lanceolata	X			X	
	Plantago major		X		X	
	Polygonum sp.					X
	Polygonum arenastrum				X	
	Polygonum persicaria	X	X			

	Polystichum munitum		X	X		
	Potentilla anserina					X
	Pteridium aquilinum			X	X	X
	Raphanus sativus				X	
	Rumex acetosella	X		X	X	
	Rumex crispus	X				
	Rumex conglomeratus	X			X	
	Satureja douglasii	X		X		
	Silybum marianum				X	
	Sisyrhinchium californica					X
	Solanum sp.				X	
	Sonchus asper			X		X
	Stachys ajugoides	X		X		
	Urtica dioica		X	X		
	Vicia sp.	X				
	Vicia sativa		X			
	Xanthium spinosum				X	
Grasses	*Aira caryophyllea*	X		X		
	Agrostis sp.	X		X	X	
	Avena barbata			X	X	
	Briza minor				X	
	Bromus californica			X		
	Bromus carinatus		X			
	Bromus diandrus	X		X	X	
	Bromus hordeaceus	X		X	X	
	Calamagrostic nutkaensis					X
	Crypsis schoenoides		X			
	Cynosurus echinatus	X		X	X	
	Dactylis glomerata				X	
	Elymus glaucus			X		
	Festuca arundinacea	X				
	Holcus lanatus	X	X	X	X	X
	Hordeum murinum	X			X	
	Lolium multiflorum	X			X	
	Polypogon monspeliensis				X	

	Vulpia bromoides	X		X		
Wetlands	*Carex* sp.	X	X			X
	Carex obnupta					X
	Cicuta maculata			X		
	Conium maculatum	X	X	X		
	Eleocharis sp					X
	Equisetum sp.		X	X		
	Glyceria leptostachya		X			
	Hydrocotyle ranunculoides					X
	Hypericum anagalloides					X
	Juncus balticus					X
	Juncus bufonius		X			X
	Juncus effusus	X	X	X	X	X
	Juncus phaeocephalus					X
	Mimulus guttatus					X
	Phalaris arundinacea	X	X			
	Phalaris aquatica				X	
	Polygonum punctatum	X	X	X		
	Ranunculus flammula					X
	Scirpus sp.			X		
	Scirpus cernuus					X
	Sparganium eurycarpum	X	X		X	

TABLE 3. Dating of Sediments for the Five Point Reyes Sediment Cores.

Site Name	**Core**	**Laboratory Number**	**Depth (cm)**	**Age (^{14}C, ^{210}Pb, ^{137}Cs, Historic)**	**S.D. (±)**	**^{13}C/^{12}C**	**Cal Age (BP) (2 s.d.)**	**Median Probability (used for graphing)**	**Calibration**	**Date Type**	**Material**
Wildcat Lake	1	pollen	70	1850 AD[1]	N/A	N/A	100	100	N/A		
	1	Beta-155421	417	2000	40	-26.9	1867 - 2060	1951	CALIB 5.0	AMS	Wood
	1	Beta-125979	1074-1080	3110	60	-25	3258 - 3391	3329	CALIB 5.0	Bulk	Sediment
Glenmire	3	pollen	90	1880 AD[2,3]	N/A	N/A	70	70	N/A		
	3	Beta-157440	127-128	1240	40	-30.9	1068 - 1270	1179	CALIB 5.0	AMS	Douglas-fir needles
	3	Beta-157441	156	1710	40	-26.8	1536 - 1708	1619	CALIB 5.0	AMS	Douglas-fir needles
	3	Beta-157442	183	1650	50	-26.3	1413 - 1631	1551	CALIB 5.0	AMS	Wood
	3	Beta-125978	240-250	5410	110	-25	5982 - 6402	6189	CALIB 5.0	Bulk	Sediment
Coast Trail Pond	1	USC Geology	7.5	1963 AD	N/A	N/A	-13	-13	N/A	137Cs	N/A
	1	pollen	62	1850 AD[4]	N/A	N/A	100	100	N/A	Pollen	N/A
	1	Beta-181984	111-112	modern	N/A	-27.1	N/A	N/A	N/A	AMS	Terrestrial organics
	1	Beta-181985	248-249	7100	50	-25.6	7835 - 8013	7939	CALIB 5.0	AMS	Terrestrial organics
	1	Beta-184995	328-329	9040	40	N/A	10173 - 10249	10215	CALIB 5.0	AMS	Charred material
	1	Beta-181986	451-452	12,260	80	-27.7	13910 - 14611	14145	CALIB 5.0	AMS	Wood
Shutter Ridge Pond	1	pollen	17	1840 AD[5]	N/A	N/A	110	110	N/A	Pollen	N/A
	1	Beta-184996	37	2780	40	-22.9	2778 - 2966	2878	CALIB 5.0	AMS	Charred material
	1	Beta-184997	84-85	30	40	-24.9	Not used	Not used	Not used	AMS	Charred material
Creamery Bay Bog	1	USC Geology	5.5	1963 AD	N/A	N/A	-13	-13	N/A	137Cs	N/A
	1	USC Geology	10	1902 AD	N/A	N/A	48	48	N/A	210Pb	N/A
	1	pollen	27.5	1840 AD[6]	N/A	N/A	110	110	N/A	Pollen	N/A

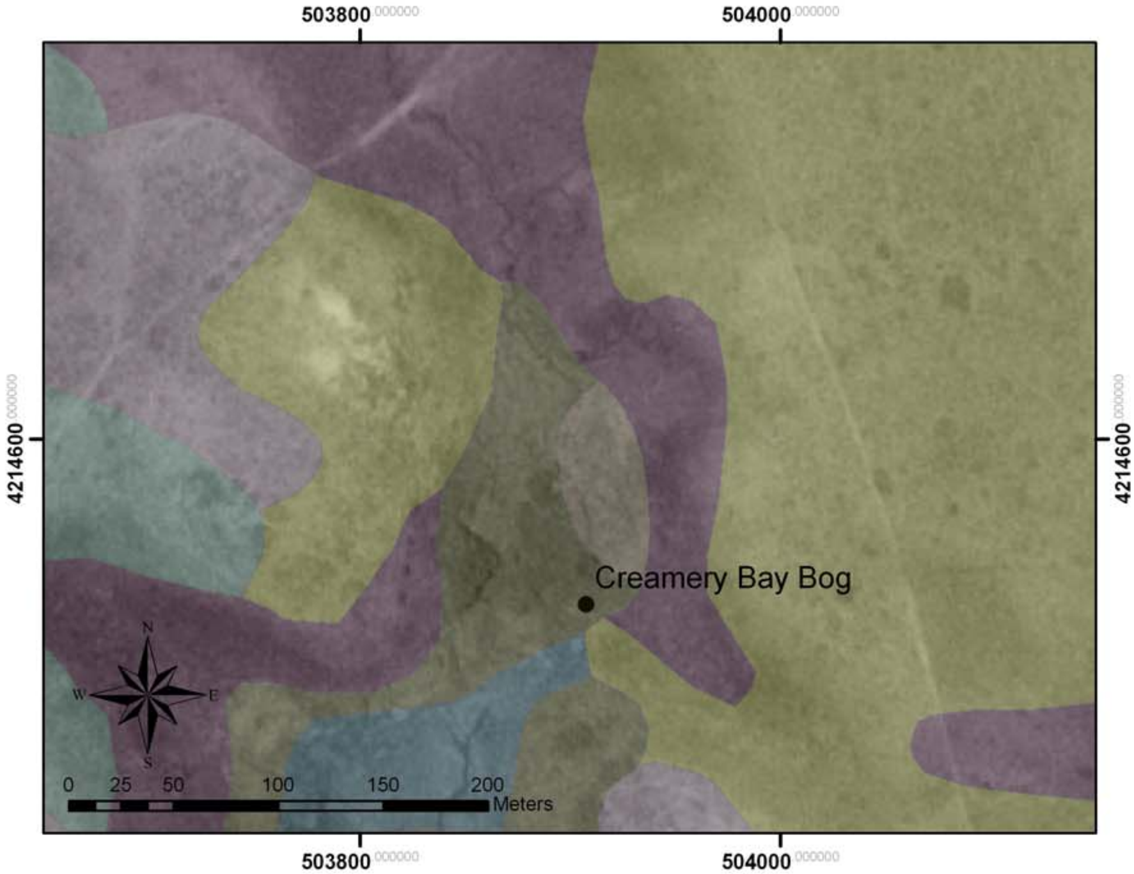
	1	Beta-183871	117-118	9010	40	-25	10148 - 10246	10202	CALIB 5.0	AMS	Charcoal
	1	Beta-183872	168	6170	50	-28	6939 - 7178	7070	CALIB 5.0	AMS	Wood twig

[1] Livingston (1994, p. 437; Shafter ran cattle here in the 1850's and 1860's)
[2] Livingston (1994, p. 433; Origins of this ranch are "elusive")
[3] Livingston (1994, p. 200-201; *Eucalyptus* trees were planted near here as early as 1870)
[4] Since this site is close to Wildcat Ranch, call it 1850
[5] Livingston (1994, p. 214; This may be one of the earliest ranches on the Peninsula – 1840?)
[6] Livingston (1994, p. 173: "F" Ranch, one of the earliest, home built here about 1842 or 1843)

TABLE 4. Linear and Polynomial Curves used to calculate Sediment Accumulation Rates

SITE NAME	**SEGMENT**	**CURVE TYPE**	**EQUATION**
Creamery Bay Bog	A (Historic)	Linear	Age = 5.79 * [Depth] – 52
	B (Holocene	Linear	Age = 111.5 (Depth) – 295.7
Shutter Ridge Pond	A (Historic)	Linear	Age = 9.529 * [Depth] - 52
	B (Holocene)	Linear	Age = 138.4 * [Depth] – 224.3
Wildcat Lake	A (Historic)	Linear	Age = 2.114 * [Depth] - 48
	B (Holocene)	Linear	Age = 5.334 * [Depth] – 273.4
	C (Holocene)	Linear	Age = 2.078 * [Depth] + 1084
Glenmire	A (Historic)	Linear	Age = 1.311 * Depth – 48
	B (Holocene)	2^{nd} Order Polynomial	Age = 0.1522 * $[Depth]^2$ – 12.11 * [Depth])
Coast Trail Pond	A (Historic)	Linear	Age = -2.46 * [Depth]) -52
	B (Holocene)	4^{th} Order Polynomial	Age = 0.000001791 * $[Depth]^4$ – 0.001789 * $[Depth]^3$ + 0.5732 * $[Depth]^2$ – 27.8 * [Depth] + 45.26

Creamery Bay Bog Core Site



Legend

● Core Site

Corrdinate System:
Projection - Universal Transverse Mercator (UTM)
Datum - North American Datum of 1983 (NAD 83)
Zone - 10 North

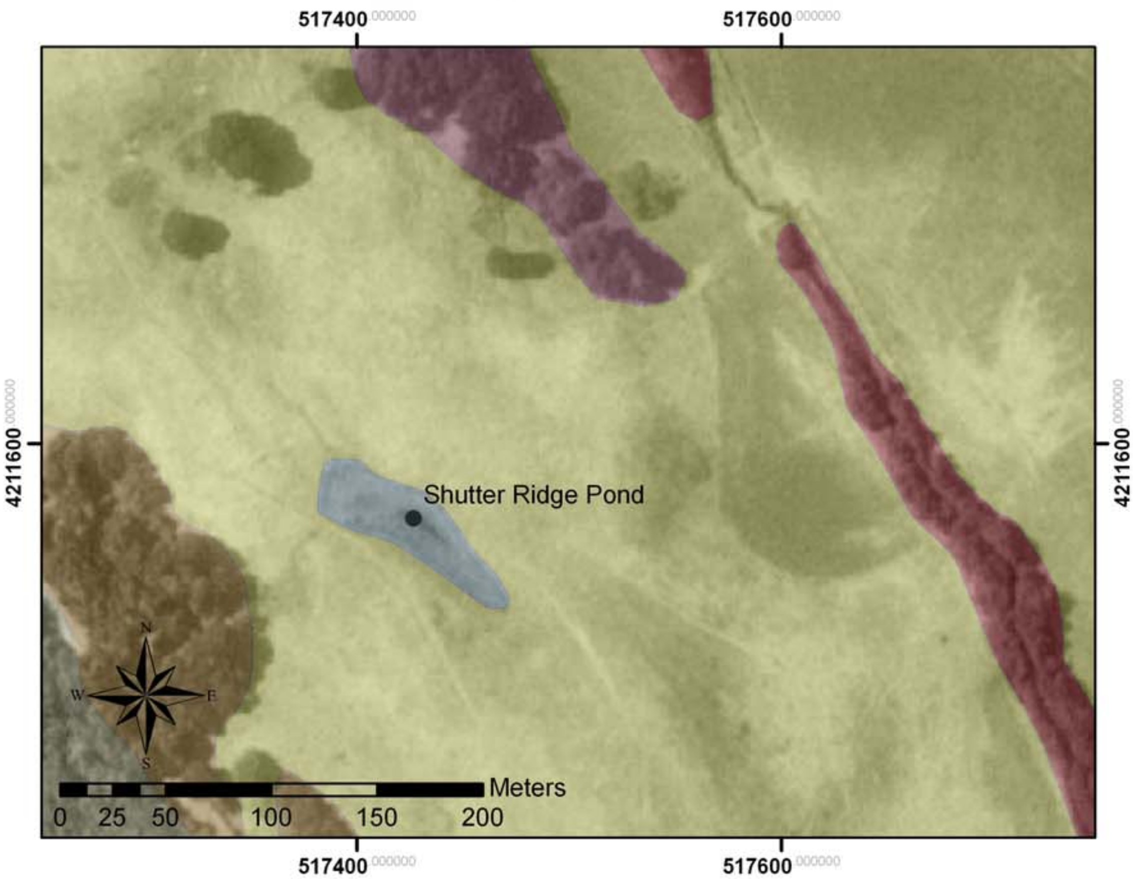
Point Reyes National Seashore Vegetation Map

ALLIANCE

- Bulrush - Cattail - Spikerush Marsh Mapping Unit
- California Annual Grassland Mapping Unit
- Coyote Brush
- Pickleweed
- Rush
- Saltgrass
- Tufted Hairgrass

Figure 1

Shutter Ridge Pond Core Site



Legend

● Core Site

Corrdinate System:
Projection - Universal Transverse Mercator (UTM)
Datum - North American Datum of 1983 (NAD 83)
Zone - 10 North

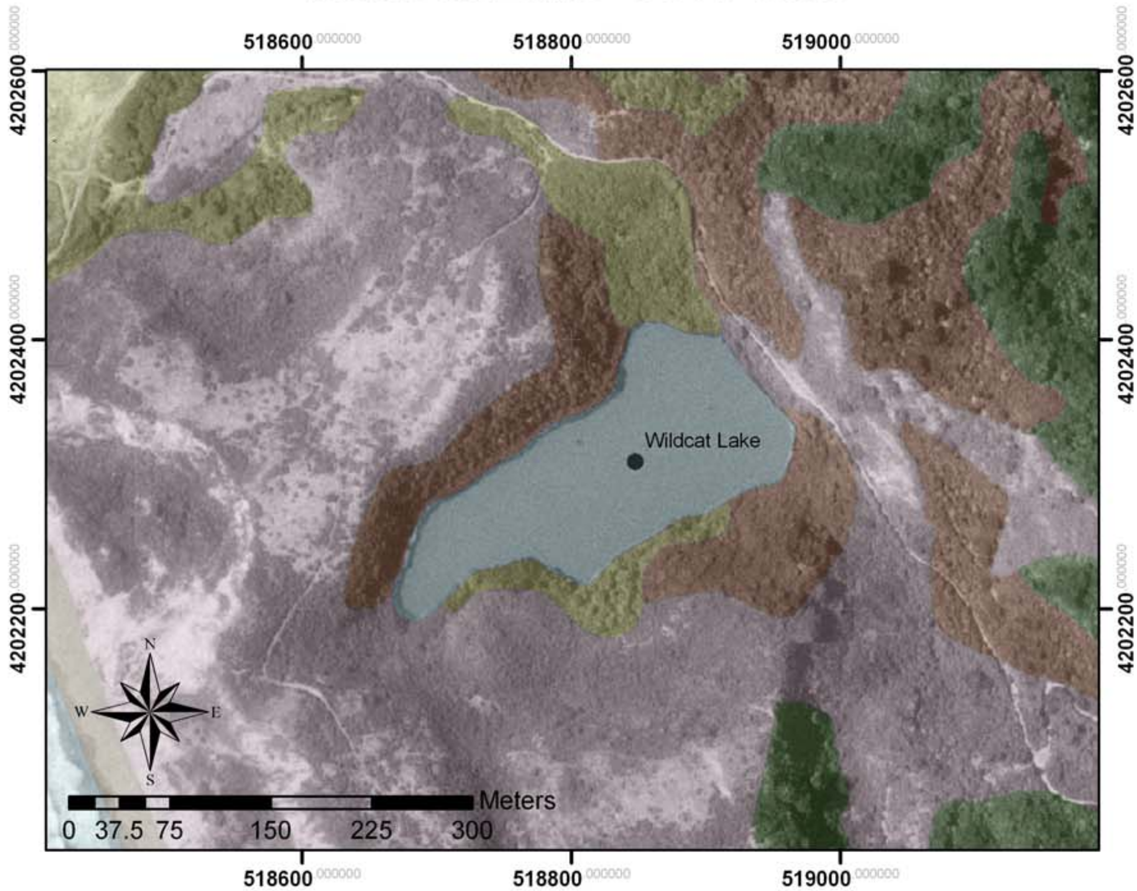
Point Reyes National Seashore Vegetation Map

ALLIANCE

- Arroyo Willow
- California Annual Grassland Mapping Unit
- California Bay
- Coast Live Oak
- Red Alder
- Water

Figure 2

Wildcat Lake Core Site



Legend

● Core Site

Corrdinate System:
Projection - Universal Transverse Mercator (UTM)
Datum - North American Datum of 1983 (NAD 83)
Zone - 10 North

Point Reyes National Seashore Vegetation Map

ALLIANCE

- Arroyo Willow
- Beaches or Mudflats
- California Annual Grassland Mapping Unit
- Coffeeberry
- Coyote Brush
- Douglas-fir
- Water

Figure 3

Glenmire Core Site

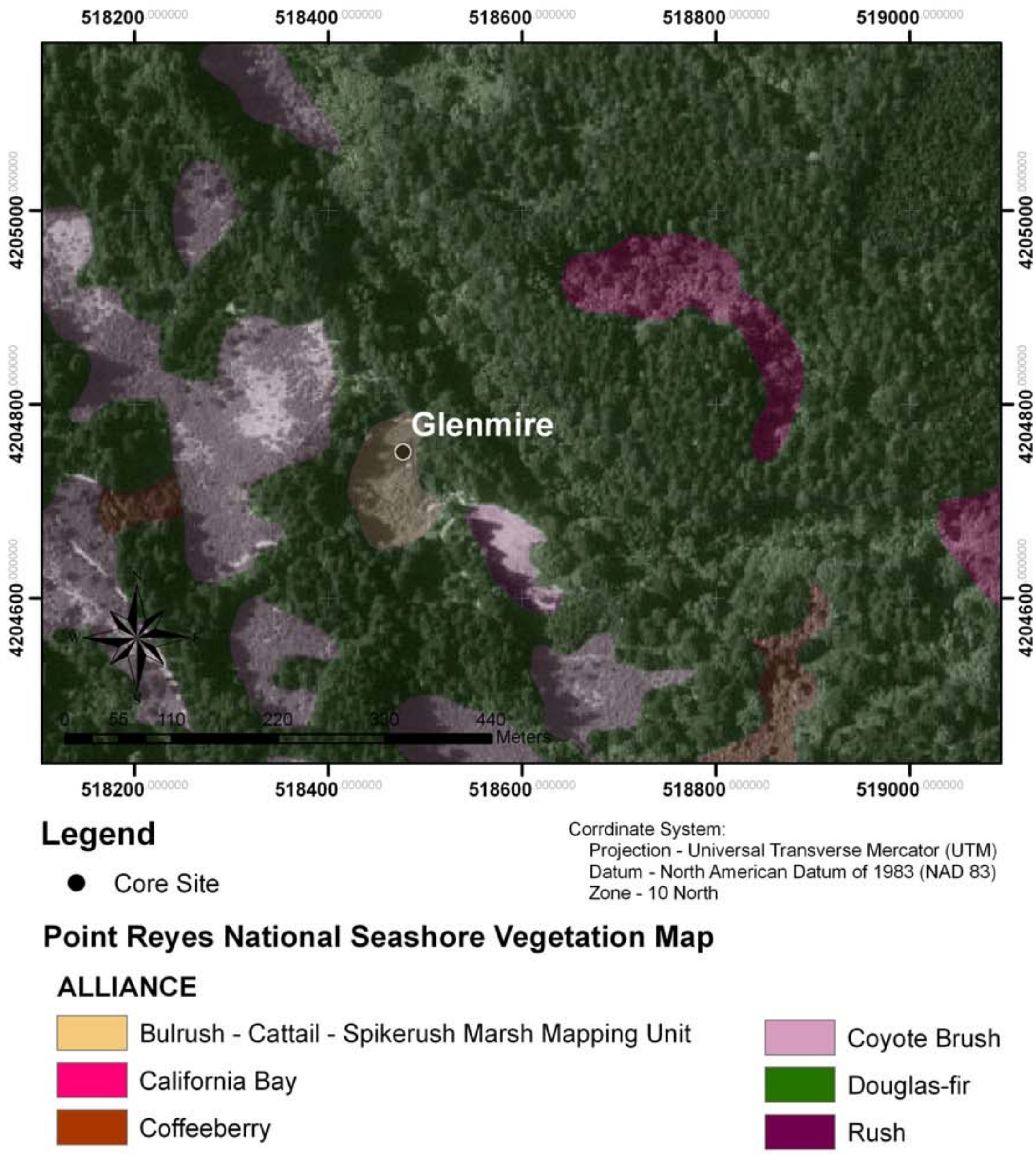
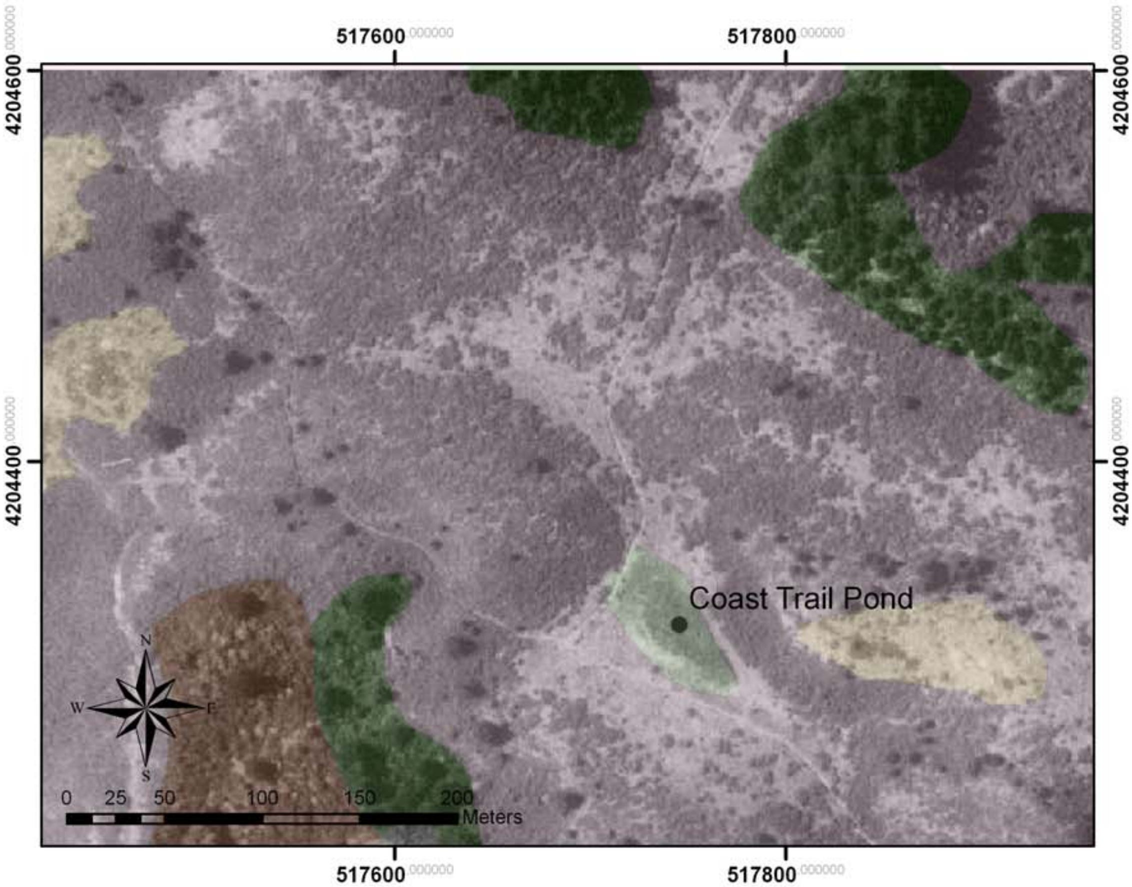


Figure 4

Coast Trail Pond Core Site



Legend

● Core Site

Corrdinate System:
Projection - Universal Transverse Mercator (UTM)
Datum - North American Datum of 1983 (NAD 83)
Zone - 10 North

Point Reyes National Seashore Vegetation Map

ALLIANCE

- California Annual Grassland with Native Component Mapping Unit
- Coffeeberry
- Coyote Brush
- Douglas-fir
- Introduced Coastal Perennial Grassland Alliance

Figure 5

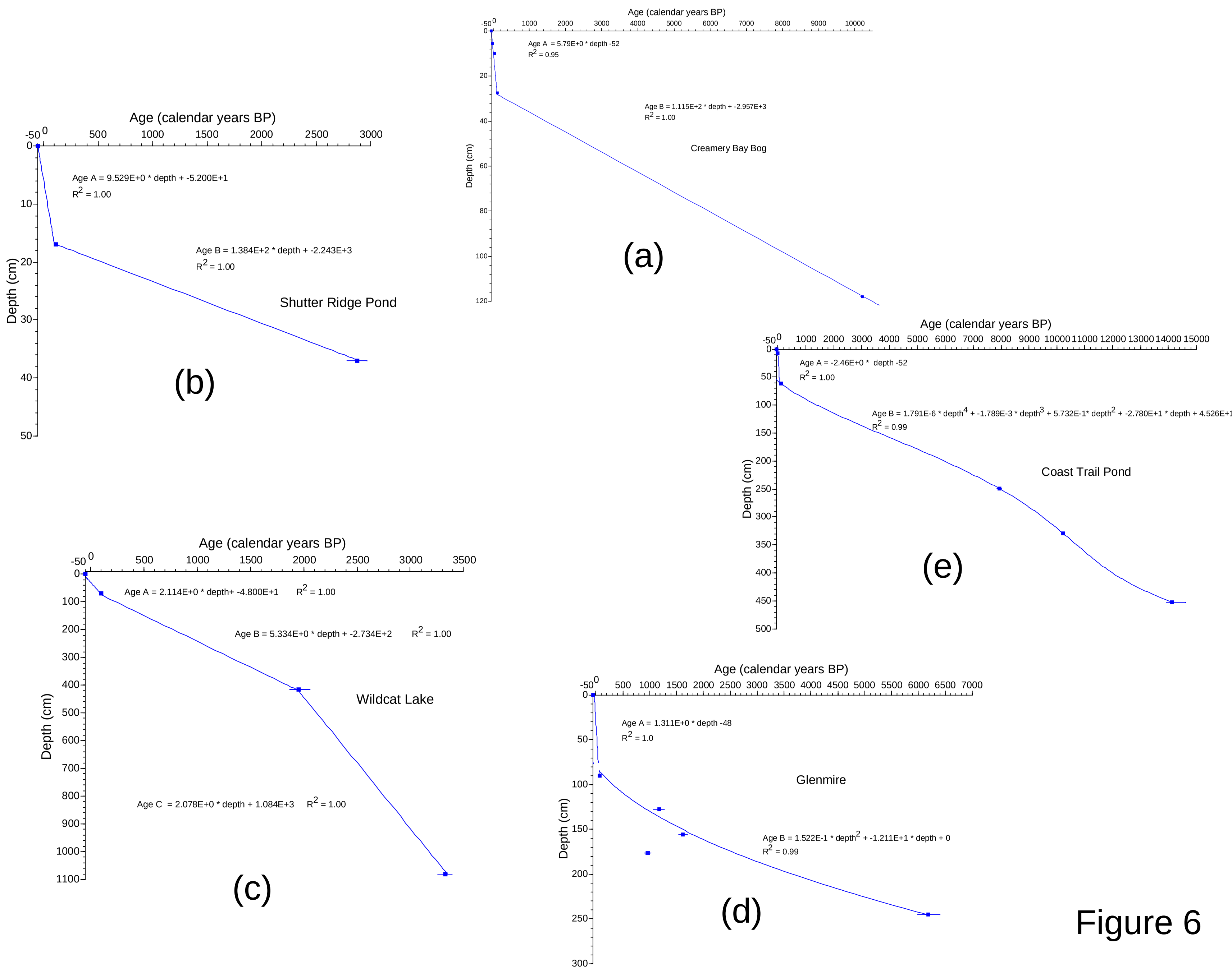
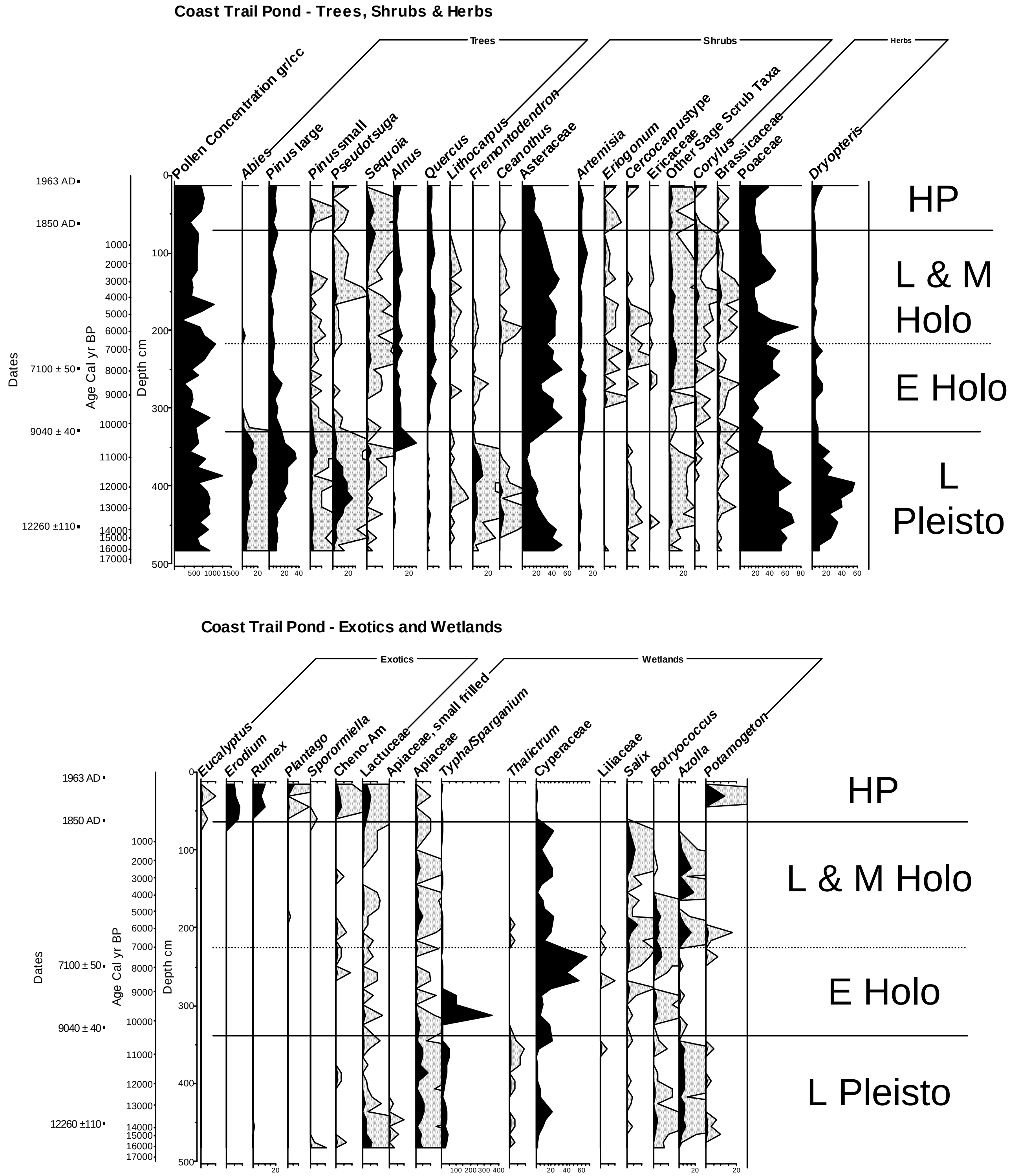
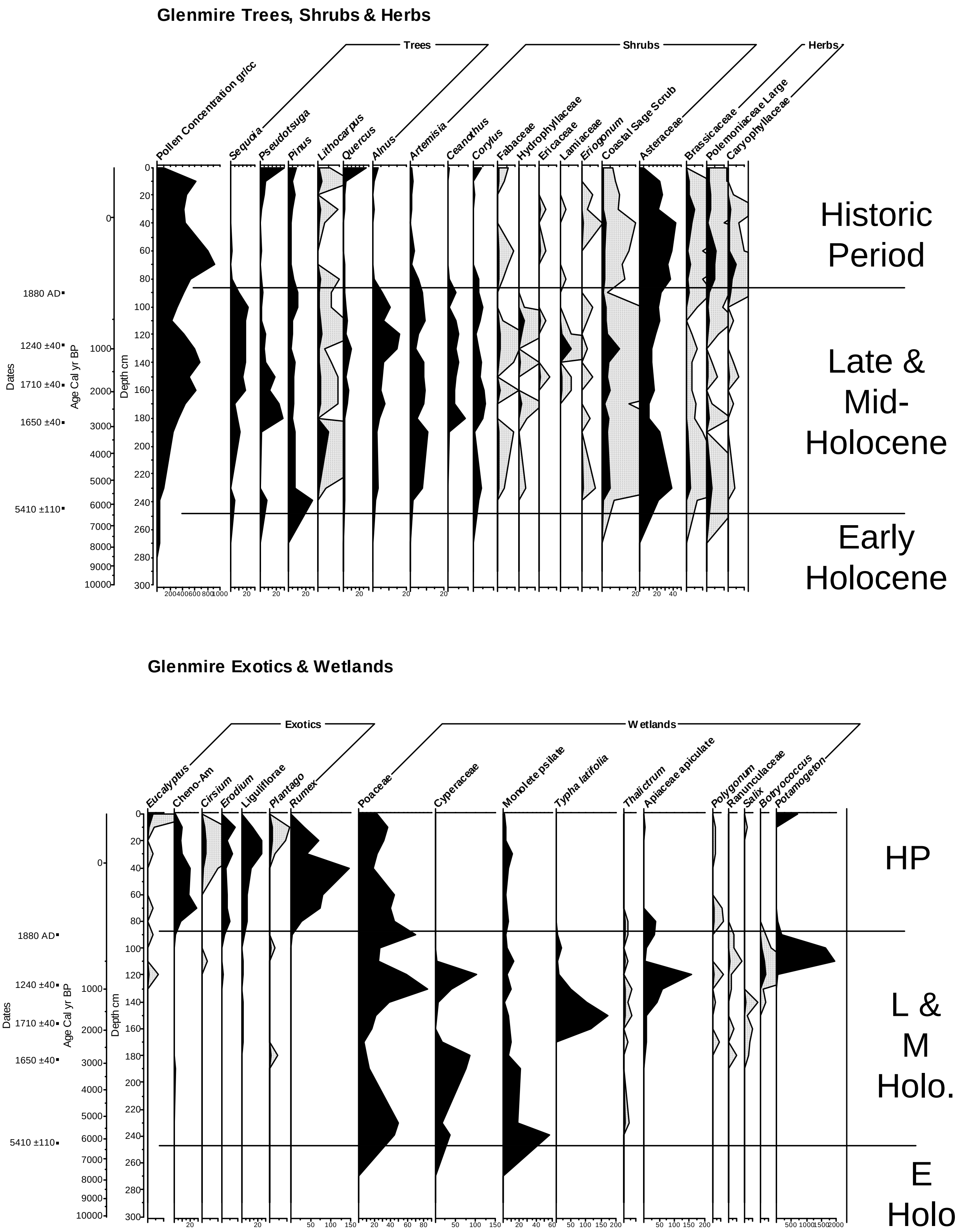

Age (calendar years BP)
Depth (cm)
Age A = 9.529E+0 * depth + -5.200E+1
R2 = 1.00
Age B = 1.384E+2 * depth + -2.243E+3
R2 = 1.00
Shutter Ridge Pond
(b)
Age A = 5.79E+0 * depth -52
R2 = 0.95
Age B = 1.115E+2 * depth + -2.957E+3
R2 = 1.00
Creamery Bay Bog
(a)
Age A = -2.46E+0 * depth -52
R2 = 1.00
Age B = 1.791E-6 * depth4 + -1.789E-3 * depth3 + 5.732E-1* depth2 + -2.780E+1 * depth + 4.526E+1
R2 = 0.99
Coast Trail Pond
(e)
Age A = 2.114E+0 * depth+ -4.800E+1 R2 = 1.00
Age B = 5.334E+0 * depth + -2.734E+2 R2 = 1.00
Wildcat Lake
Age C = 2.078E+0 * depth + 1.084E+3 R2 = 1.00
(c)
Age A = 1.311E+0 * depth -48
R2 = 1.0
Glenmire
Age B = 1.522E-1 * depth2 + -1.211E+1 * depth + 0
R2 = 0.99
(d)

Figure 6



Coast Trail Pond - Trees, Shrubs & Herbs
Trees
Shrubs
Herbs
Pollen Concentration gr/cc
Abies
Pinus large
Pinus small
Pseudotsuga
Sequoia
Alnus
Quercus
Lithocarpus
Fremontodendron
Ceanothus
Asteraceae
Artemisia
Eriogonum
Cercocarpus type
Ericaceae
Other Sage Scrub Taxa
Corylus
Brassicaceae
Poaceae
Dryopteris
Dates
Age Cal yr BP
Depth cm
1963 AD
1850 AD
7100 ± 50
9040 ± 40
12260 ±110
HP
L & M Holo
E Holo
L Pleisto
Coast Trail Pond - Exotics and Wetlands
Exotics
Wetlands
Eucalyptus
Erodium
Rumex
Plantago
Sporormiella
Cheno-Am
Lactuceae
Apiaceae, small frilled
Apiaceae
Typha/Sparganium
Thalictrum
Cyperaceae
Liliaceae
Salix
Botryococcus
Azolla
Potamogeton

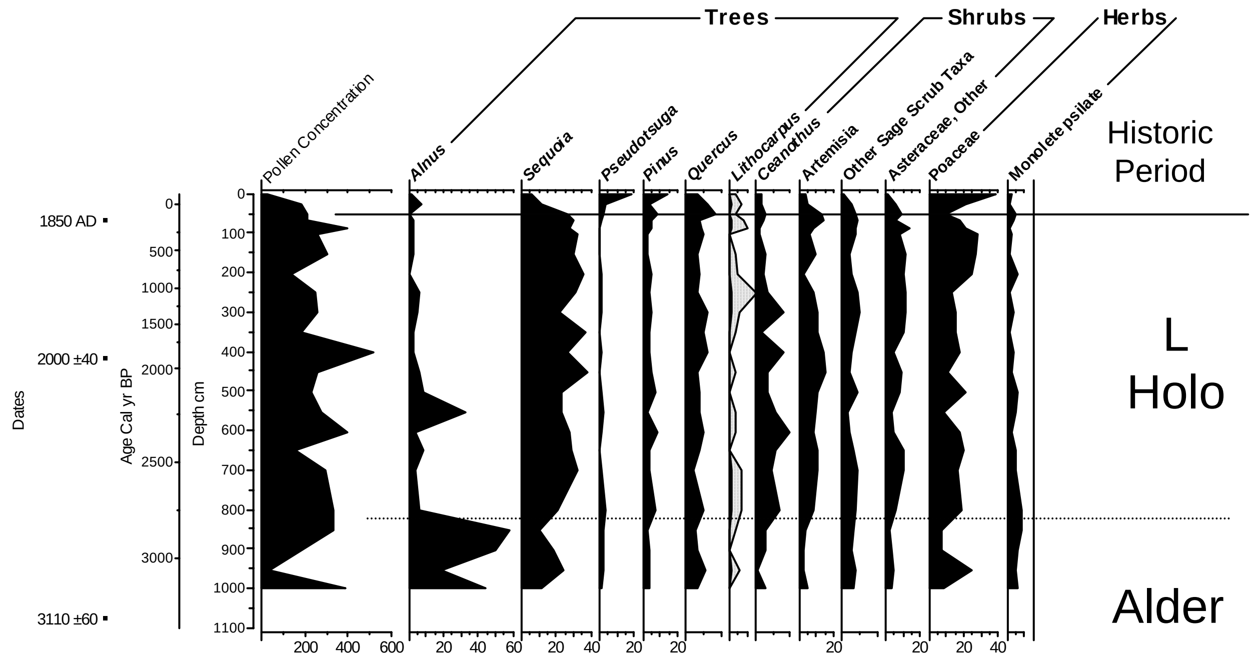
Figure 7



Glenmire Trees, Shrubs & Herbs
Trees
Shrubs
Herbs
Pollen Concentration gr/cc
Sequoia
Pseudotsuga
Pinus
Lithocarpus
Quercus
Alnus
Artemisia
Ceanothus
Corylus
Fabaceae
Hydrophyllaceae
Ericaceae
Lamiaceae
Eriogonum
Coastal Sage Scrub
Asteraceae
Brassicaceae
Polemoniaceae Large
Caryophyllaceae
Dates
Age Cal yr BP
Depth cm
1880 AD
1240 ±40
1710 ±40
1650 ±40
5410 ±110
Historic Period
Late & Mid-Holocene
Early Holocene
Glenmire Exotics & Wetlands
Exotics
Wetlands
Eucalyptus
Cheno-Am
Cirsium
Erodium
Liguliflorae
Plantago
Rumex
Poaceae
Cyperaceae
Monolete psilate
Typha latifolia
Thalictrum
Apiaceae apiculate
Polygonum
Ranunculaceae
Salix
Botryococcus
Potamogeton
HP
L & M Holo.
E Holo

Figure 8

Wildcat Lake Trees, Shrubs & Herbs



Wildcat Lake Exotics & Wetlands

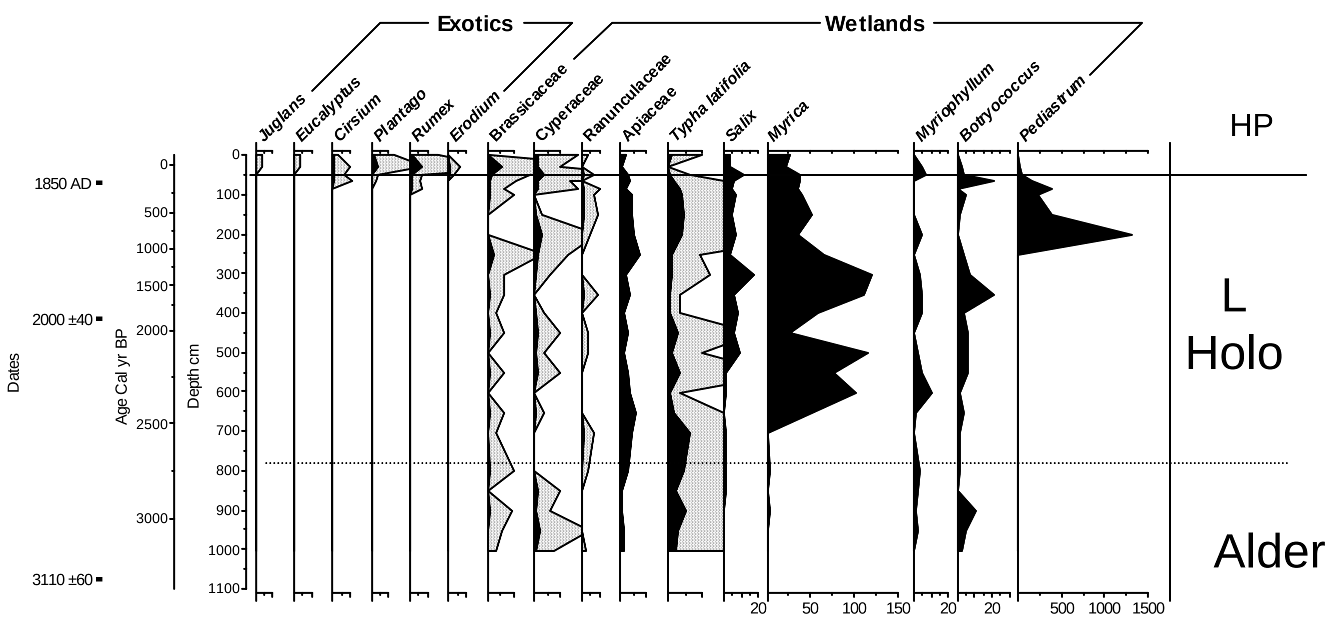
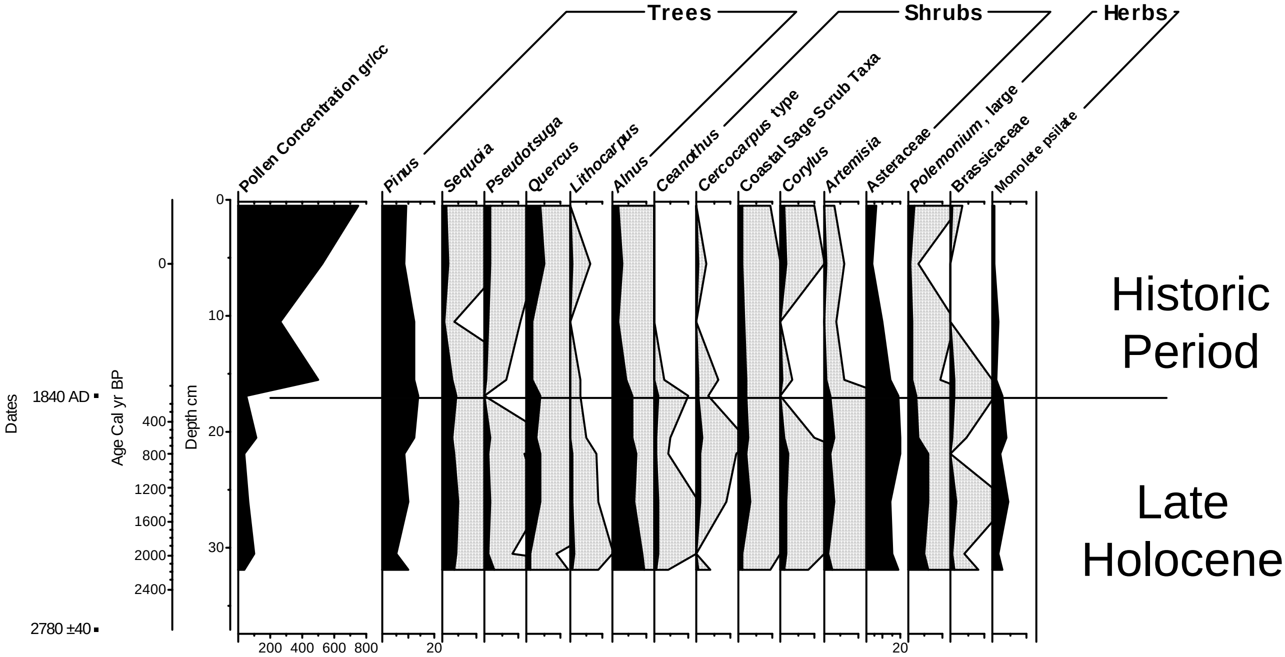


Figure 9

Shutter Ridge Pond Trees, Shrubs & Herbs



Shutter Ridge Pond Exotics & Wetlands

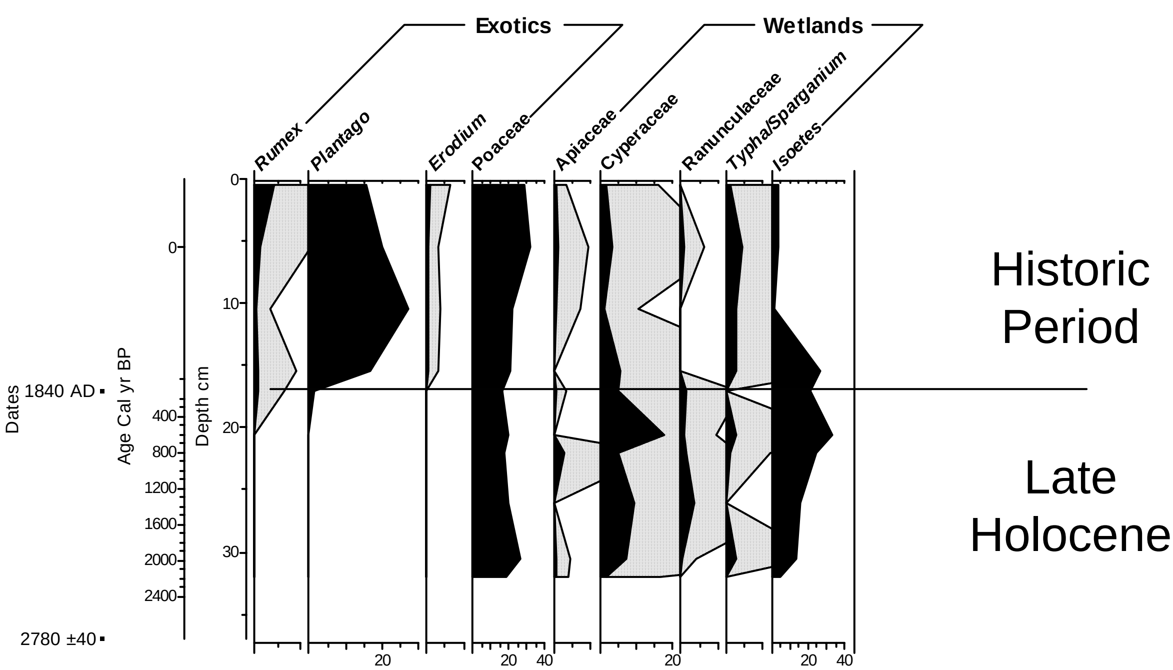
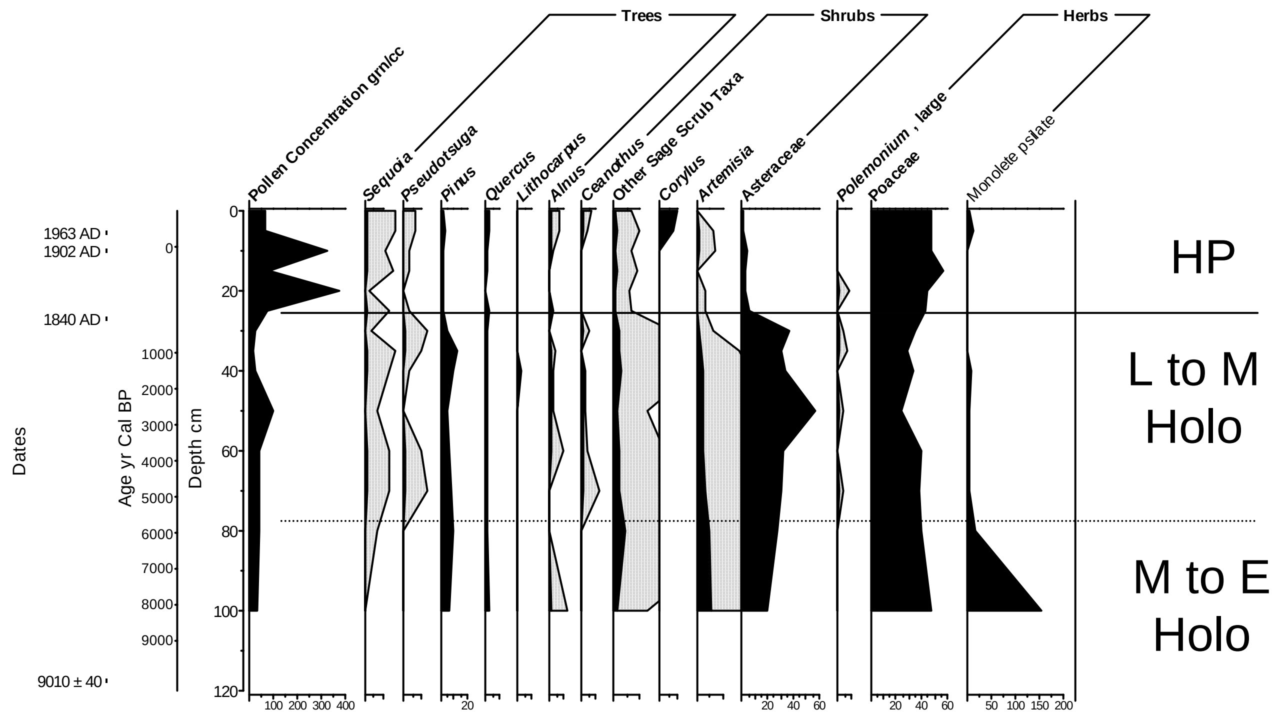


Figure 10

Creamery Bay Bog - Trees, Shrubs & Herbs



Creamery Bay Bog - Exotics & Wetlands

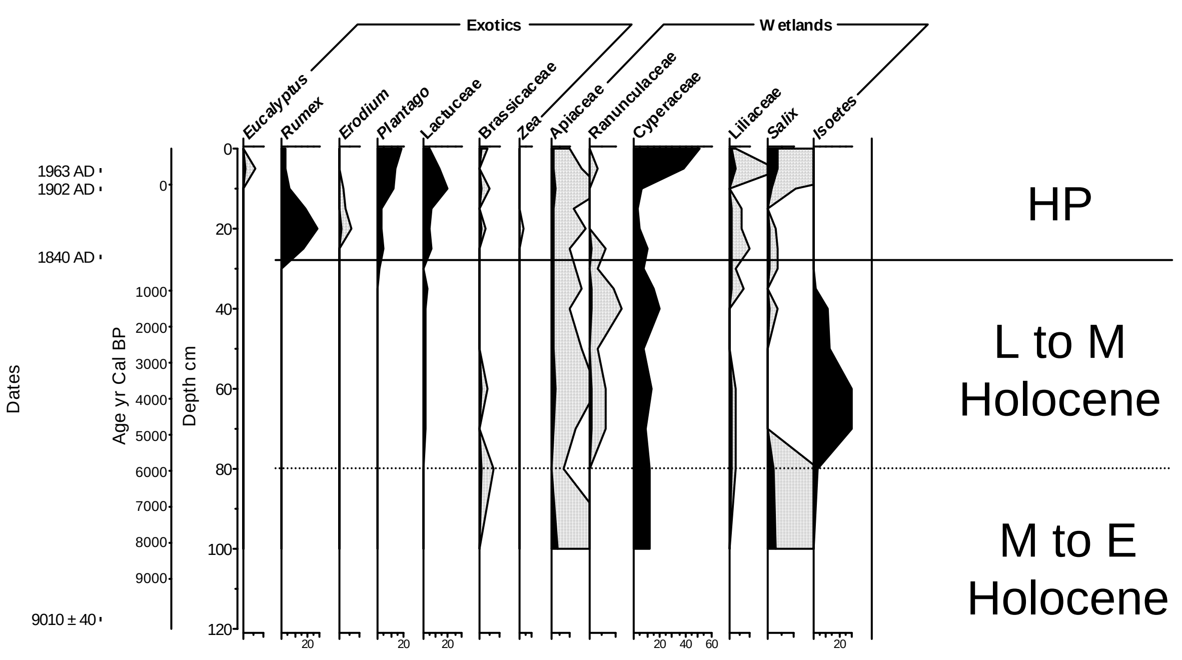
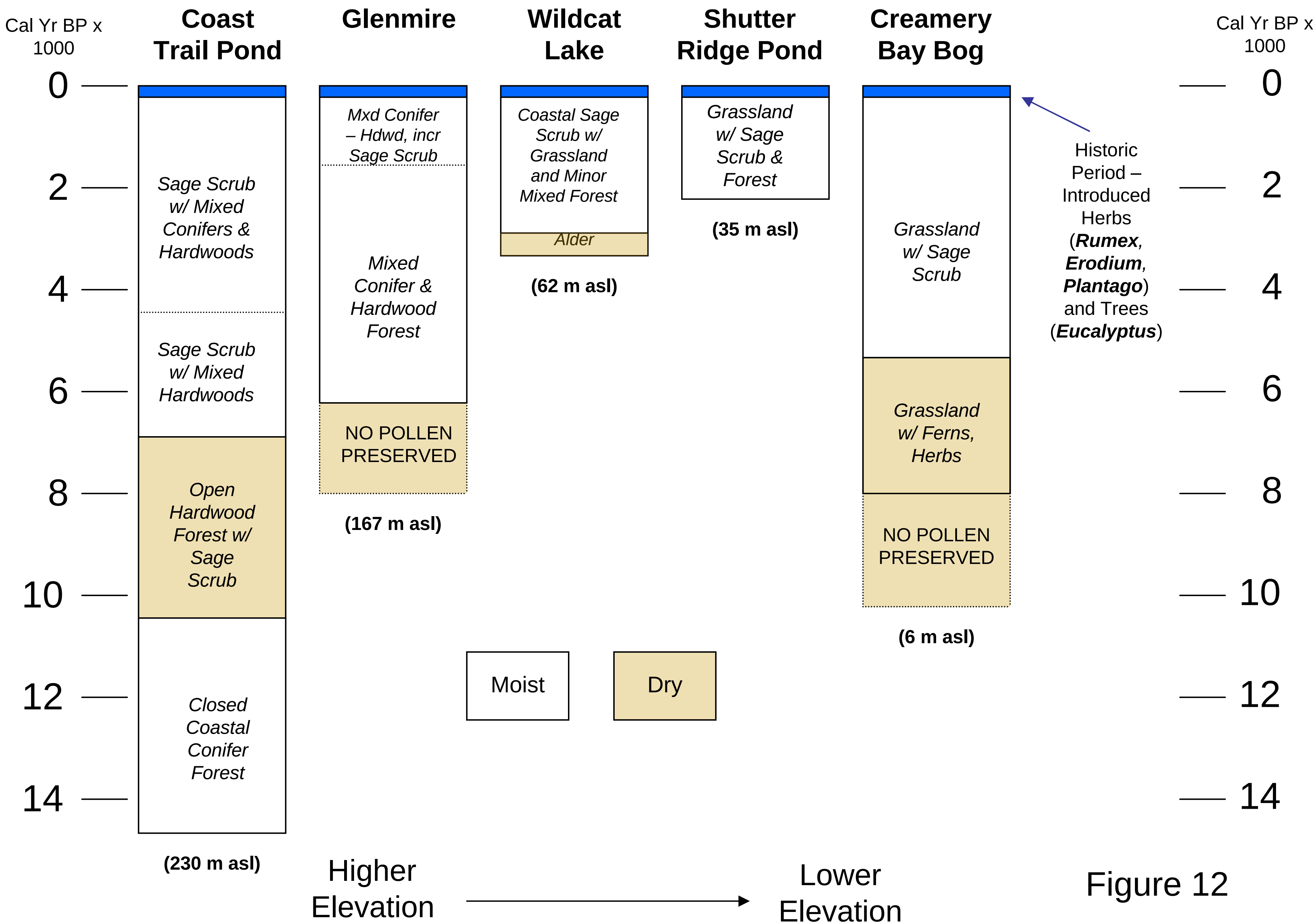


Figure 11



Cal Yr BP x 1000
Coast Trail Pond
Glenmire
Wildcat Lake
Shutter Ridge Pond
Creamery Bay Bog
Cal Yr BP x 1000
0
2
4
6
8
10
12
14
Sage Scrub w/ Mixed Conifers & Hardwoods
Sage Scrub w/ Mixed Hardwoods
Open Hardwood Forest w/ Sage Scrub
Closed Coastal Conifer Forest
(230 m asl)
Mxd Conifer – Hdwd, incr Sage Scrub
Mixed Conifer & Hardwood Forest
NO POLLEN PRESERVED
(167 m asl)
Coastal Sage Scrub w/ Grassland and Minor Mixed Forest
Alder
(62 m asl)
Grassland w/ Sage Scrub & Forest
(35 m asl)
Grassland w/ Sage Scrub
Grassland w/ Ferns, Herbs
NO POLLEN PRESERVED
(6 m asl)
Historic Period – Introduced Herbs (Rumex, Erodium, Plantago) and Trees (Eucalyptus)
Moist
Dry
Higher Elevation
Lower Elevation

Figure 12

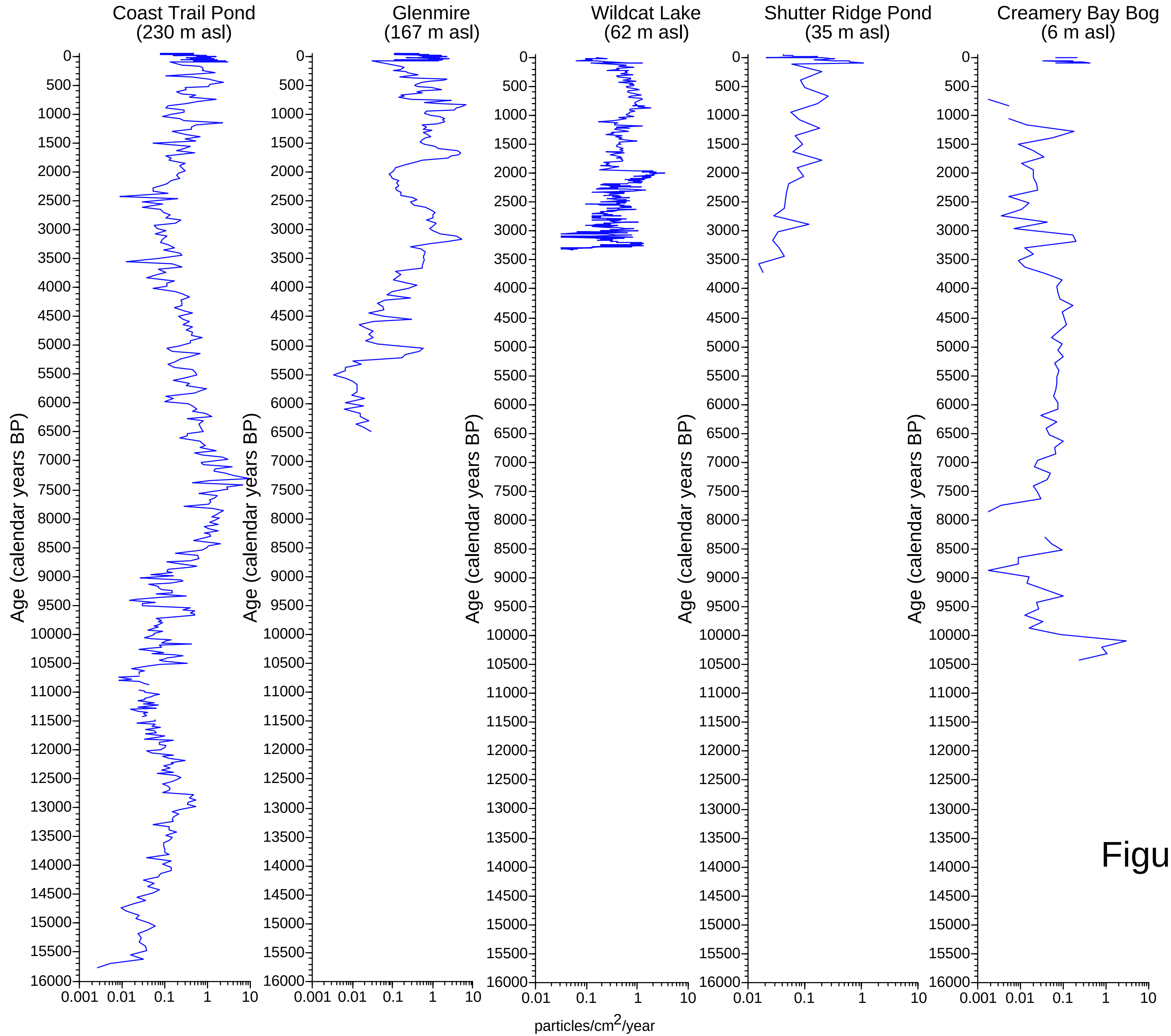

Coast Trail Pond (230 m asl)
Glenmire (167 m asl)
Wildcat Lake (62 m asl)
Shutter Ridge Pond (35 m asl)
Creamery Bay Bog (6 m asl)
Age (calendar years BP)
particles/cm2/year
0.001 0.01 0.1 1 10
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500 7000 7500 8000 8500 9000 9500 10000 10500 11000 11500 12000 12500 13000 13500 14000 14500 15000 15500 16000

Figure 13